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VIRTUALISATION OF PRODUCT DEVELOPMENT/ DESIGN – SEEN FROM DESIGN THEORY AND METHODOLOGY

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ABSTRACT
This paper looks at the terms “Virtual Prototyping”, “Virtual Engineering”, “Virtual Product Development” and “Virtual Reality” from the perspective of Design Theory and Methodology (DTM). DTM should be the base discipline for investigating, systemising and improving product development/ design processes, but has not yet come to a decisive viewpoint about the implications and use of the terms mentioned.

Keywords: Design Theory and Methodology, Virtual Prototyping, Virtual Engineering, Virtual Product Development, Virtual Reality

1 INTRODUCTION

Over the last decade terms like “Virtual Prototyping”, “Virtual Engineering”, “Virtual Product Development” and “Virtual Reality” have been propagated. These terms mostly come from other disciplines and stakeholders (e.g. from developers of computer tools, computer science in general) and their use still is somewhat “messy”. Starting from Design Theory and Methodology, the aims of this paper are:

- To get Design Theory and Methodology (DTM) involved into the discussion about the “virtualisation” of product development/design;
- Based on an adequate theoretical background, to make proposals for the terminology, the role of virtual methods and tools and their further development.

The theoretical background chosen is the approach of CPM/PDD (Characteristics-Properties Modelling, Property-Driven Development/Design). The CPM/PDD approach was heavily inspired by work on new computer tools in the 1990s and has turned out to be a useful concept for systemising the development and application of computer support in product development/design. This is why it is chosen as the basic concept for the considerations in this paper.
CPM/PDD has been explained in more detail in several earlier publications, the most relevant for the topic discussed here being [1-3].

2 THE TERM „VIRTUAL“

The origin of the term “virtual” is the Latin word “virtus” (virtue/goodness, braveness, competence, power, manhood, virility). Its derivatives changed their meaning considerably over time. A search for current definitions of the term “virtual” displays results like (here according to [4]):

1. almost or nearly as described, but not completely or according to strict definition: the virtual absence of border controls
2. Computing: not physically existing as such but made by software to appear to do so: virtual images; see also virtual reality
3. Optics: relating to the points at which rays would meet if produced backwards
4. Mechanics: relating to or denoting infinitesimal displacements of a point in a system
5. Physics: denoting particles or interactions with extremely short lifetimes and (owing to the uncertainty principle) indefinitely great energies, postulated as intermediates in some processes

Especially no. 2 will be relevant for our considerations. In this context, Berthier explains in [5]: “The current standard meaning of ‘virtual’, inherited from medieval Scholastics (and from the invention it made of the pseudo-Latin virtualis), entails ‘not in actual fact’”. However, he strongly objects the wide-spread concept of the “virtual” being merely “potential”; he claims that something virtual can have actual effects, and therefore defines “‘virtual’ as that which is not real but displays the full qualities of the real, in a plainly actual – i.e. not potential – way”.

For the same reasons as in [5] some sources argue that the term "virtual" should **not** be contrasted with "real", but with "physical" (see e.g. [6]). This seems very sensible especially for the area of product development/design as "virtual" methods and tools mainly challenge traditional "physical methods" – and, depending on the type of experiment, "physicality" does not automatically imply the "reality" of the final product.

However, in this general sense product development/design always has been "virtual" to a large extent: Always a non-physical, i.e. "virtual" model (mental model, sketch, drawing, CAD model, …) has to exist first which has to display at least some "qualities" [5] of the physical artefact into which it is to be transferred. The only new thing today is that – for reasons of time and cost savings – we try to determine as many "qualities" as possible in the virtual world, i.e. we try to shift the transfer to the physical world to as late as possible.

As a last remark concerning terminology, it should be noted that terminological details become even more complicated if we look at different languages: "Virtuel" or "virtuell" in French and German, respectively, do not cover identical meanings as "virtual" in the English language.

3 THEORETICAL BACKGROUND (CPM/PDD)

As has been stated in the introduction the theoretical background of this paper is the CPM/PDD approach (Characteristics-Properties Modelling, Property-Driven Development/Design), [1-3]. CPM is the **product** modelling side; while PDD explains (development/design) **process** phenomena.

The CPM/PDD approach is based on the distinction between the characteristics (in German: "*Merkmale*") and properties ("*Eigenschaften*") of a product:

- **Characteristics** (**C_i**) are made up of the structure, shape, dimensions, materials and surfaces of a product ("*Struktur und Gestalt*", "*Beschaffenheit*"). They can be directly influenced or determined by the development engineer/designer.
- **Properties** (**P_j**) describe the product's behaviour, e.g. function, weight, safety and reliability, aesthetic properties, but also things like manufacturability, assemblability, testability, environmental friendliness, and cost. They cannot be directly influenced by the developer/designer.

The characteristics are very similar to Hubka & Eder's [7] "internal properties", to Suh's [8] "design parameters" or what Birkhofer et al. [9] call "independent properties". The properties, as introduced here, are related to the "external properties", as defined in [7], the "functional requirements"in [8] and the "dependent properties" as used in [9]. For reasons discussed in other papers, Andreasen's [10] nomenclature "characteristics/properties" is retained here.

Characteristics and properties are two different concepts for describing products and their behaviour, respectively. As mentioned previously, the concepts have been used in DTM for a long time. The only new aspect of CPM/PDD is that this duality is in the **centre** of modelling products and product development/design processes.

To handle characteristics and properties – literally thousands of them in complex products – and to keep track of them in the development process they have to be structured. Figure 1 shows the basic concept, as discussed in CPM/PDD:

- On the left, a proposition for the (hierarchical) structuring of characteristics is given, following the parts' structure (or tree) of a product. It complies with standard practice, and links considerations to the data structures of CAx systems.
- On the right, a proposition for the top-level headings of structuring properties is presented, based on life-cycle criteria, and reflecting frequently discussed issues in product development/design.

On the characteristics (left) side of Figure 1, an additional block is drawn that represents dependencies (**D_x**) between characteristics. Development engineers and designers are familiar with these types of dependencies, e.g. geometric or spatial dependencies, as well as those concerning fits, surface and material pairings, even conditions of existence. Geometric and spatial dependencies can now be captured and administered by parametric CAD or PDM systems.

Figure 1 also shows the two main relationships between characteristics and properties:

- **Analysis:** Based on known/given characteristics (structural/design parameters) of a product, its properties can be determined (and therefore, its behaviour), or – if the product does not yet exist – predicted. In principle, analyses can be carried out using experiments (using physical models or a prototype) or virtually (by conventional calculation and/or using simulation tools).

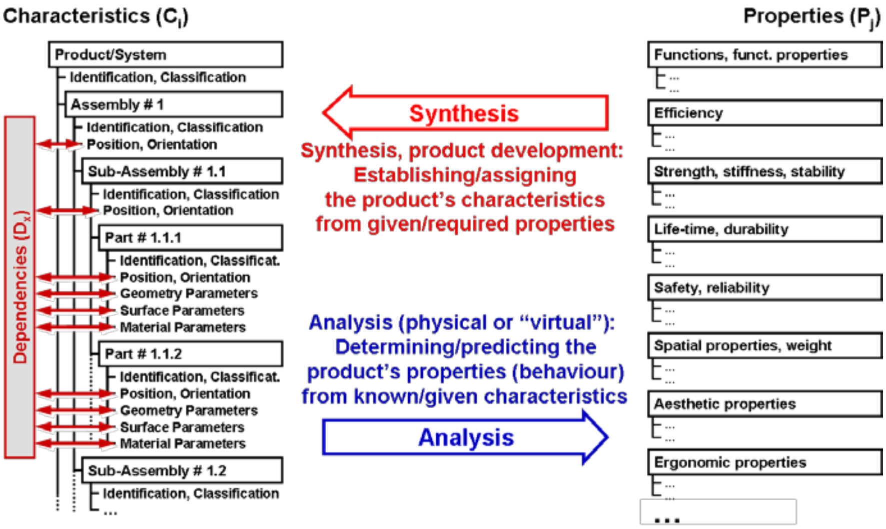

Figure 1. Characteristics and properties, and their two main relationships.

- **Synthesis:** Based on given, i.e. required, properties, the product's characteristics are established and appropriate values assigned. Synthesis is the main activity in product development: The requirements list is, in principle, a list of required properties – the task of the development engineer/designer is to find appropriate solutions, i.e. an appropriate set of characteristics that meet the requirements to the customer's satisfaction.

In the CPM/PDD approach, analysis and synthesis, as the two main relationships between characteristics and properties, are modelled in more detail, following a network-like structure. Figure 2 and Figure 3 show the two basic models for analysis and synthesis, respectively.
The expressions used in figs. 2, 3 and in all subsequent figures have the following meaning:

$\mathbf{C_i}$:	Characteristics ("Merkmale")	$\mathbf{R_j}, \mathbf{R_j^{-1}}$:	Relations between characteristics and properties (and vice versa)
$\mathbf{P_j}$:	Properties ("Eigenschaften")	$\mathbf{D_x}$:	Dependencies ("constraints") between characteristics
$\mathbf{PR_j}$:	Required Properties		
$\mathbf{EC_j}$:	External conditions		

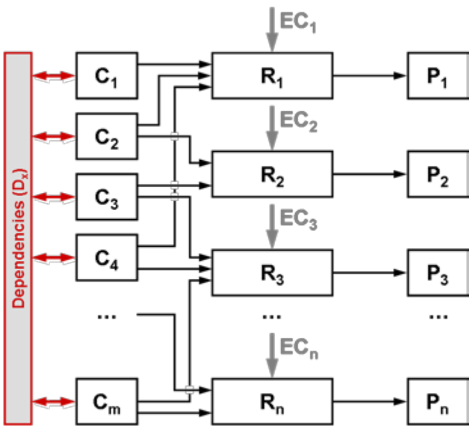

Figure 2. Basic model of analysis

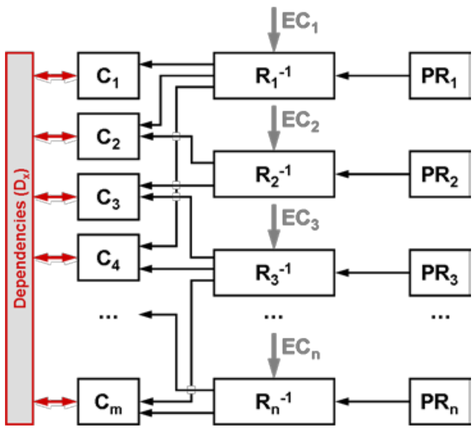

Figure 3. Basic model of synthesis

For reasons of simplification, a simple list (or vector) structure is displayed as an idealisation for both characteristics ($\mathbf{C_i}$) and properties ($\mathbf{P_j}$, $\mathbf{PR_j}$, respectively). During product development/design, the finished product does not yet exist. Therefore, the "relation boxes" ($\mathbf{R_j}$, $\mathbf{R_j^{-1}}$) have to be represented by appropriate methods and tools; these can be based on physical or non-physical, for example, "virtual" methods.
As will be shown later, models, methods and tools to realise the relation-boxes for analysis ($\mathbf{R_j}$) shown in Figure 2 are of particular interest for our further considerations. They can be based on very different approaches:

- Guesswork, estimation
- Experience
- Interrogation (e.g. customers)
- Physical tests/experiments
- Tables, diagrams (= formalised experience & experimental knowledge)
- Conventional/simplified calculations
- Computer tools

The determination/prediction of every product property via an appropriate model, method/tool must be performed with respect to certain external conditions (**EC_j**). They define the framework in which the statement about the respective property is valid.

When using computer methods/tools for analysis (as well as synthesis), an additional influence factor has to be considered: The validity of a statement about a property is not only dependent on the characteristics (**C_i**) and the assumed external conditions (**EC_j**), but also on the modelling conditions (**MC_j**), [3]. They must be clearly defined and stated (by providers and users of the method/tool) so that the use and results of the respective tool are not compromised. For example, results of an FEM analysis can only be interpreted if the element types, meshing and boundary conditions implied are known – all of these having nothing to do with the real problem, only with its "conditioning" for the computer.

Explanations so far have only covered product-modelling (CPM). A process model (PDD) develops from CPM when the evolution of characteristics and properties is followed over time: Product development/design is a process consisting of cycles, each of them implying the following steps (Figure 4):

1. **Synthesis:** Starting from required properties (**PR_j**), characteristics (**C_i**) of the future solution are established. This can be achieved by "pure synthesis" (original design) or by adopting partial solutions from previous designs, catalogues, etc.
2. **Analysis:** In this step, the current properties (**P_j**, as-is properties) of the solution state are analysed, based on the characteristics established so far. In this step, the properties that went into the preceding synthesis step are analysed, as well as all other relevant properties (as far as is possible at this time).
3. **Determining individual deviations:** Next, the results of the analysis (as-is properties) are compared with the required properties, the deviations between the two (**ΔP_j**) representing the shortcomings of the current design.
4. **Overall evaluation:** The development engineer/designer now has to run an overall evaluation; extracting the main problems and deciding how to proceed, that is, pick out the property/properties to be addressed next and select appropriate methods and tools for the subsequent synthesis-analysis-evaluation cycle.

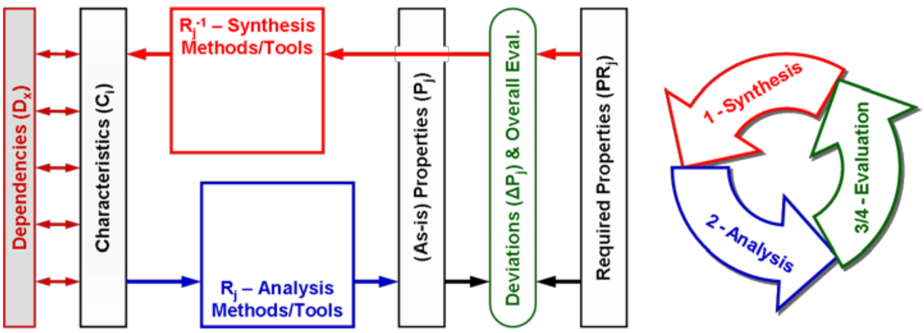

Figure 4. Scheme of the product development/design process consisting of cycles of synthesis-analysis-evaluation steps

From one cycle to the next, because of each synthesis step, more and more characteristics are established and their values assigned ("detailing" the structural description of the solution). The analysis steps of all cycles all deal with the same properties repeatedly – but with a modified and/or extended set of characteristics, thus creating increasingly precise information about the product's properties/behaviour. Consequently, the analysis methods and tools have to switch from being rough to increasingly exact and detailed as the process progresses.

The product development process as a whole is controlled or driven by the evaluation of the gap between required and as-is properties at the end of each cycle. The process can successfully terminate if and when:

- all characteristics needed for manufacturing and assembly of the product are established and assigned (**C_i**)
- all (relevant) properties can be determined/predicted (**P_j**)
- with sufficient certainty and accuracy
- all determined/predicted properties are close enough to the required properties, i.e. the "deviation vector" becomes minimal ($\underline{\Delta P_j} \rightarrow \underline{0}$).

4 VIRTUALISATION OF PRODUCT DEVELOPMENT/DESIGN

In this section an attempt is made to define and discuss different terms created in connection with the virtualisation of product development/design process, based on the CPM/PDD-concept explaining these processes (see section 3, in particular Figure 4). The term "virtual" is used in meaning no. 2 according to the terminological considerations of section 2 (i.e. "virtual" = not physically existing as such but made by software to appear to do so).

4.1 Virtual Prototyping (VP)

"Virtual Prototyping" can now be defined as constructing computer-based representations of an artefact that may physically not yet exist (Figure 5). The "Virtual Prototype" (or: the "Virtual Product", [11]) as the result consists of:

1. Characteristics (design parameters, **C_i**) defining the (present state of the) artefact definition (parts' structure with assembly information, geometry of components, materials, surfaces).
2. Dependencies between characteristics (**D_x**): they are not absolutely essential, but make modifications of ("playing around" with) and further detailing of the Virtual Prototype – as is part of the synthesis steps in product development/design – much easier.

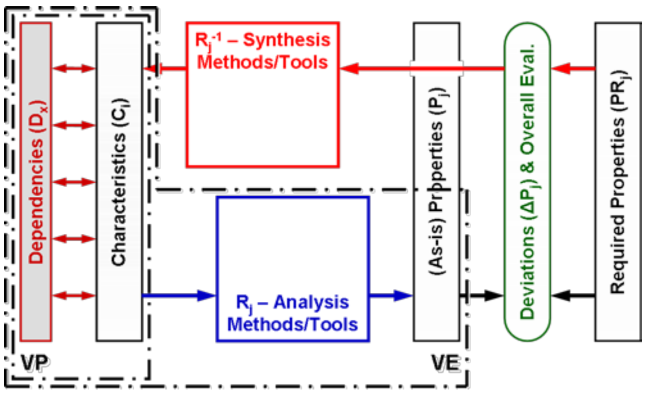

Figure 5. Placing Virtual Prototyping (VP) and Virtual Engineering (VE) in the scheme of the product development/design process according to Figure 4

The input of Virtual Prototyping comes from one or more preceding synthesis step(s) where the characteristics are established and assigned. The output of the Virtual Prototype must serve Virtual Engineering (see next sub-section), i.e. provide the data for subsequent analysis methods/tools.

Thus, the term "Virtual Prototyping" is defined here similar to "Physical Prototyping" which also denotes building the means (the prototype) but does not contain doing the subsequent tests.

Quite a lot of support systems necessary to build and represent Virtual Prototypes already exist (here with focus on mechanical characteristics):

- CAD[1] and PDM[1] systems capture the no. 1 items (parts' structure, geometry, material, surfaces).
- In addition, CAD and PDM systems can represent at least some of the no 2 items (dependencies between characteristics) – if they have parametric functionalities. In these systems, dependencies are usually restricted to geometric dependencies; the range is, however, being extended continuously ("Knowledge-Based Engineering").

It has to be considered that in product development/design we do not have just one Virtual Prototype but several/many according to the synthesis-analysis-evaluation cycles of the process (see section 3); the difference between them is that from one cycle to the next the number of characteristics already established and their assigned values change (detailing and varying the evolving solution, respectively). Unfortunately this has been widely neglected in discussions about Virtual Prototyping – probably due to the fact that these discussions are dominated by software and data structure aspects and not so much by application, i.e. product development/design aspects.

[1] CAD – Computer-Aided Design; PDM – Product Data Management.

It should be noted that the definition of the term "Virtual Prototyping" presented here does not at all contain statements about data formats etc. of the Virtual Prototype. The authors of this paper consider these questions as a secondary matter – to be solved after issues of contents are settled.

4.2 Virtual Engineering (VE)

"Virtual Engineering" can now be defined as applying analysis methods/tools to Virtual Prototypes in order to predict the relevant properties (the relevant behaviour) of the – not yet physically existing – artefact (Figure 5).

"Virtual Engineering" includes "Virtual Prototyping" as defined in sub-section 4.1; in addition, it contains:

3. Appropriate analysis methods/tools ($\mathbf{R_j}$) – in Virtual Engineering mainly computer-based – for the prediction of the relevant properties (the relevant behaviour, $\mathbf{P_j}$) without physical mock-ups, prototypes and related experiments.
4. External conditions ($\mathbf{EC_j}$) and modelling conditions ($\mathbf{MC_j}$) defining the context in which the results obtained by the analysis methods/tools are valid.

The output of Virtual Engineering are statements about the relevant (as-is) properties (the relevant behaviour) of the Virtual Prototype – required for the next development/design process, i.e. determining the deviations from the required properties.

Again, we find a large and still increasing range of existing support systems for Virtual Engineering:

- Analysis methods/tools (items according to no. 3) are represented by so-called CAE[2] systems; the most general and commercially available ones (for mechanical engineering) are FEA, MBS, CFD systems.
- Items according to no. 4 (external conditions, modelling conditions) belong to the analysis methods/tools – at least implicitly –; for reasons of clarity they are not shown in Figure 5.

For some of the properties the effort to be made for analysis is quite minimal; in these cases the results of Virtual Engineering are practically the same as the output of Virtual Prototyping. Examples are:

- Assessing shapes from an aesthetic viewpoint: we can not calculate/simulate "aesthetic behaviour", so have to show geometry directly to the human for assessment.
- Checking simple motions (without dynamic effects): the tools used for product definition (CAD) and for Virtual Prototyping usually can readily represent motion (= "geometry in time") without having to add further tools.

In other cases (e.g. motion studies including dynamic effects, mechanical stress and strain, fluid dynamics) quite sophisticated additional tools are required to derive statements on the behaviour of the Virtual Prototype.

The challenges of Virtual Engineering are:

- All analysis methods/tools implied in Virtual Engineering must be assigned specifically to the product properties to be analysed. However, for different types of products different sets of properties are relevant [2] which would result in a huge number of specialised analysis tools to cover all needs. In contrast, both in software development and application we prefer "standard solutions" which, in consequence, can only cover some, however quite general classes of properties. The challenge here is to provide useful and economically viable computer support for the large variety of properties in many industries and companies.
- As the CPM/PDD approach demonstrates, even for the same property several methods/tools are needed, according to the state of the development/design process: In the "early stages" only a small number of characteristics are established and assigned; they require methods/tools that can deliver statements about properties without being fed with many details. "Late phases" are defined by much more detailed descriptions of the solution (many characteristics assigned); only then will elaborate tools and methods be applicable. Therefore, putting as much functionality as possible on the computer is questionable. The challenge is to find answers to the question: In which process stages do "conventional" methods/ tools remain useful and efficient, from which stages are computer-based methods/tools superior?
- Finally: How to achieve a seamless flow of methods/tools for different properties and for use in different stages of the process? This question addresses more than interface issues: Interfacing

[2] CAE – Computer-Aided Engineering (used in the meaning of "calculation and simulation"); FEA – Finite Element Analysis; MBS – Multi-Body Simulation; CFD – Computational Fluid Dynamics

particular software components still has a very static view; what we need are dynamic concepts which can follow the evolution (= change and growth) of product characteristics and knowledge about product properties along the whole development/design process where even the methods/ tools for the analysis of the same properties can change from one stage to the next.

4.3 Virtual Product Development (VPD)

"Virtual Product Development" would now mean closing the loop, i.e. determining the deviations between the required and the as-is properties (= results from Virtual Engineering), running an overall evaluation of the deviations, drawing conclusions on the next synthesis steps (= adding or changing characteristics of the previous solution).

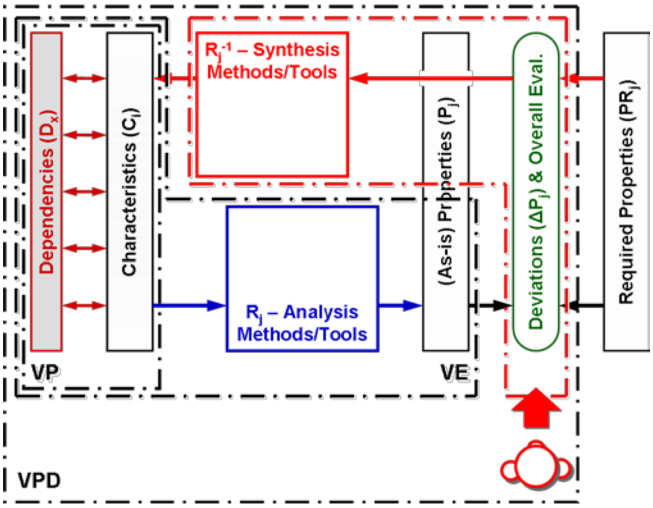

Figure 6. Virtual Product Development (VPD): closing the loop is a primarily human activity, based on Virtual Prototyping (VP) and Virtual Engineering (VE)

However, in this paper drawing conclusions out of the analysis results (deviations, overall evaluation, synthesis) is still seen as the task of the human (Figure 6), even if entirely based on analysis results obtained via Virtual Prototyping and Virtual Engineering.

The main reasons for this apparently "conservative" view: are

- We still do not have "operational" computer representations of requirements[3], especially in mechanical design; in electrical or information technology some representations exist with quantitative requirements. Without these, no comparison between analysis results (as-is properties) and required properties can be conducted (and even less so subsequent steps like overall evaluation and deciding about synthesis steps). However, finding a solution for this problem would be the first step towards realising automatic Virtual Product Development.
- The main problem of the product developer/designer today is the multitude of properties (requirements) to be considered [12]. At present, we still do not have algorithms which could perform reliable multi-criteria evaluation.
- Finally, automatic modification of characteristics (design parameters) of a previous design as the next synthesis step would require completely new strategies.

It should be mentioned that, despite these problems, two concepts of "closing the loop" by computers are known and have been utilised successfully (the first for decades):

- The use of digitised solution patterns: Typical examples are CAD features and feature libraries [13]. Much older examples are variant programmes/modules for CAD. Quite recent extensions come under the heading "Knowledge-Based Engineering" (KBE). These elements can always only cover pre-defined elements and pre-defined knowledge, so are only suitable for well known development/design problems.
- Optimisation methods/tools: In principle, they imitate synthesis-analysis-evaluation cycles, i.e. they have a "closed loop" structure. An example already commercially available is software systems for structural optimisation; a lot more are being developed and tested in research. Optimisation methods/tools can currently only handle a very limited number of properties (e.g. mechanical stress and weight in structural optimisation) – several magnitudes less than what human developers/designers cope with every day. However, a lot of research is ongoing in this field, so new solutions might come up.

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[3] "Operational" means that storing files containing statements about required properties (as in current PDM systems) and text-processing requirements lists (as in current RMS – Requirements Management Systems) is not sufficient; instead, meanings and values of properties must be captured.

4.4 Virtual Reality (VR)

For assessment of the product properties (as-is properties) during product development/design the properties have to be somehow presented to the people involved in the process [14]. This can be done utilising very different means: (columns of) figures, graphs/graphics, on paper, computer screens, etc., up to immersive presentations based on Virtual Reality (VR) technology. In the terminology of this paper, VR is a relatively new means of presenting properties (behaviour) of a product under development as close to the later physical object/prototype as possible and as early as possible. The aim is providing better (more immersive, more intuitive) assessment of product properties in order to speed up the product development/design process (Figure 7). Using VR technology supports the presentation of results obtained by Virtual Prototyping (VP) and Virtual Engineering (VE); it changes neither the basics of Virtual Product Development (VPD) nor the role of the human developer/designer in it.

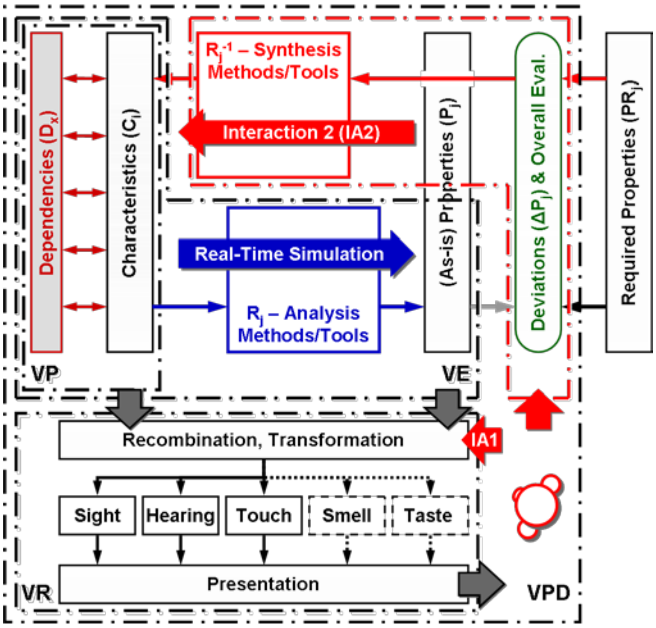

Figure 7. Virtual Reality (VR) as a tool of Virtual Product Development (VDP)

The origins and drivers of the VR technology are clearly in the entertainment sector (games, cinema, etc.). That is the main reason why VR is still strongly focussed on visualisation. In principle, however, all senses of a human user can (and should) be addressed. Here, "all senses" is taken as the five traditional senses, i.e. sight, hearing, touch, smell and taste, even if among medical and cognitive scientists a debate about the number and classification of the human senses is still ongoing.

At present, in VR technology visualisation is most advanced, e.g. using a CAVE[4] in engineering applications. A lot of research is going into developing presentation means for other senses, haptic and acoustic presentations, usually in combination with visualisation, being the most prominent, both for entertainment and engineering.

Depending on the property to be presented (for which properties does a human have receptors?), but also depending on the VR technology implied (which senses can be addressed by the equipment?) VR presentations often need metaphoric abstractions, e.g. displaying properties in false-colour presentations mapped onto the geometry or audio signals indicating certain events. This is the first reason why a recombination and transformation of both the product characteristics and the product properties is required before they can be presented in VR.

A key challenge of VR technologies is that real-time presentation and real-time interaction with the model is required. In order to fulfil this requirement, models may have to be reduced which is the second reason for (further) transformations.

The disadvantage of recombination and transformation of the Virtual Engineering results before presenting them in VR is that details and relations get lost (e.g. substituting the original parameterised geometry with tessellated surfaces for visualisation). Thus, direct interaction with the (reduced/substitute) VR model (IA1 in Figure 7) does not allow all modifications desired by the product developer/designer in order to optimise the design. Often the "big loop" is necessary, i.e. starting with a revised Virtual Prototype (IA2 in Figure 7), running through new analyses (Virtual Engineering, VE) and doing recombination and transformation again. If, under these circumstances, the real-time requirement is maintained the whole VP/VE chain has to meet it. At present, this often means implying simplified analysis methods/tools and/or using pre-calculated operational maps of the product behaviour.

The challenges for VR research and advancement, seen from the perspective of product development/design, are:

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[4] CAVE - *Cave Automatic Virtual Environment*

- In product development/design, the task of VR is to present product properties for efficient assessment. Depending on the application, many different (combinations of) properties can be involved [2]. So adaptability to different requirements of different users/use cases is the most important requirement of VR [15].
- In order to enhance the integration of VR tools into Virtual Product Development (VPD), more direct modification facilities are required: In an optimal case VR would work on the original (parameterised) Virtual Prototype and would utilise analyses of the relevant properties in real-time (Virtual Engineering), thus shortening present cascades of detached model reductions, recombinations and transformations. In consequence, at least new representation and interface standards are necessary.

5 EXAMPLE

Figure 8 briefly shows an example of a pick-and-place unit during the Virtual Product Development process which in this case implies Virtual Reality presentations in an audio-visual CAVE [16]. Based on the Virtual Prototype provided by the CAD-system and external conditions (e.g. load) a simulation model could be created, here analysing the kinematic and kinetic behaviour. By coupling the (reduced) Virtual Prototype with the simulation model an interactive audio-visual VR presentation is possible. In this case the simulation model was built in such a way that it can meet the real-time requirements. As a result, during the VR session the user can manipulate at least some of the product characteristics (e.g. design parameters such as teeth numbers of the gears in order to analyse the dynamic and, ultimately, the acoustic behaviour) as well as some external conditions (e.g. load) with a real-time adaption of the result. The details of this set-up are explained in [17].

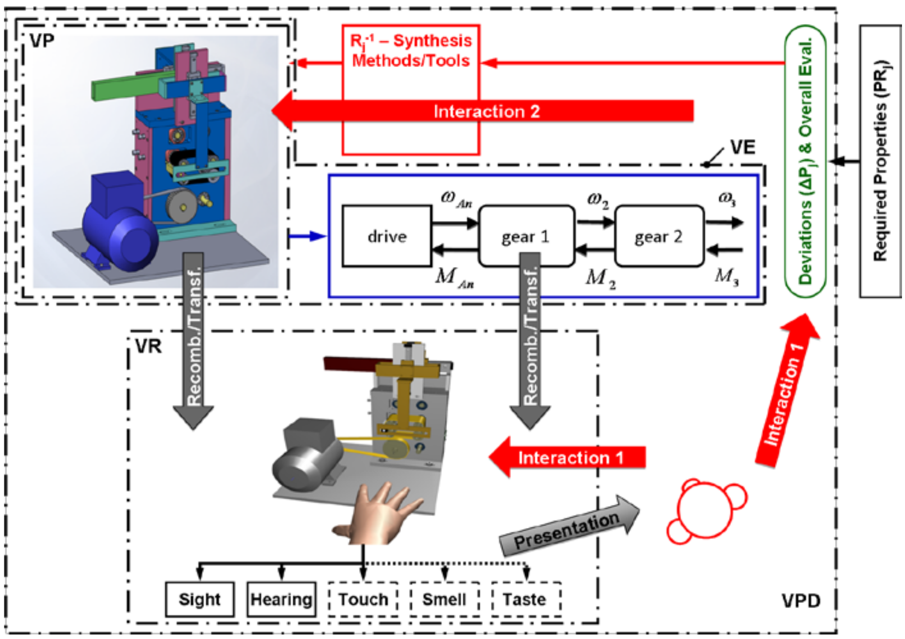

Figure 8. Virtual Product Development for the example of a pick-and-place unit

6 CONCLUSIONS

This paper delves into the terms “Virtual Prototyping”, “Virtual Engineering”, “Virtual Product Development” and “Virtual Reality” which have been brought into product development/design over the last decade, mostly by outside disciplines and stakeholders. This is done from the perspective of Design Theory and Methodology (DTM) which should be the base discipline for investigating, systemising and improving product development/design processes.

The conclusion is that the mentioned terms can be clearly distinguished by their tasks in the product development/design process. For each of them the process brings different requirements of models and methods. In order to realise efficient tools for the development engineer/designer it is crucial that these models and methods work together seamlessly and that they are extendable along the process (along the evolution of the solution of a development/design task).

The results and proposals may not present final solutions, especially as the general approach shown here may be regarded as quite particular. However, this paper is an attempt to get DTM more involved in the discussion about the virtualisation of product development/design. In an optimal situation, it will spark off broader discussion about the topic, with DTM ultimately determining the development of the supporting tools, not vice versa.

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