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Rationalizing virtual reality based on manufacturing paradigms

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Abstract

Comparing the evolvement of the manufacturing industry of the last century to the way virtual reality is used nowadays some remarkable similarities come to light. Current virtual reality equipment requires a high level of craftsmanship to achieve the maximum results, and often equipment is specially build for a dedicated process or project. While the technical revolution in the manufacturing industry led to a turnaround in which more generic production equipment were used in a structured configuration. The goal is to prevent the pitfalls already encountered in the last century in process planning, and convert the advantages of a reconfigurable manufacturing system to the way virtual reality is used.

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Keywords: Virtual Reality; Manufacturing paradigm; Tool selection

1. Introduction

Roughly since the second half of the 18th century, three technological revolutions took place. The first one introduced the use of steam engines in large scale industries. Furthermore the increased use of cast iron resulted in the ability to build larger constructions, composed from standardised parts. Larger factories arose, where the production process was characterized by division of labour and specialization, and so, ousted the craft-type workshops. Also national and international transport was undergoing revolutionary changes with the advent of railways and ocean liners.

The second technological revolution took place at the end of the 19th century. The most conspicuous technological breakthroughs were the development of the internal combustion engine, the use of electricity as an energy carrier and revolutionary innovations in the field of chemistry. The use of new construction techniques in building, such as concrete and steel framing, opened up the possibility of unprecedented high building, while sewage systems, purified water and electricity improved the formerly poor living conditions in the cities. The technical revolution led to a turnaround in which more generic production equipment were used in a structured configuration. As a consequence less artisan staff was required to operate the machinery, and machinery could be used to produce multiple products depending on the configuration. This led to the introduction of e.g. the assembly line by Ford in 1913.

The third technological revolution is currently happening. The digital revolution in information sciences, the development of new materials and the implementation of automated production processes are all part of the current revolution. The ability to make extreme miniaturization of products, especially electronic components leads to making, what was used to be high-end, technology available to every person [1].

In this article the focus is on what happened in the manufacturing industry in the second industrial revolution. What triggered the introduction of these changes, and what impact did it have on the approach to product development? What preconditions were essential to act as a catalyst for the revolution to take place? And finally, can this revolution in manufacturing be extrapolated to the currently used applications of VR in product development processes?

2. Legitimate comparison

Within the field of manufacturing, a lot of research is done on the optimization of existing processes, and the development of

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new ones. At the same time, the purpose of a manufacturing process has never changed over all these years: effectively and efficiently employ processes and resources to realise products that are in alignment with the product definition as established by the designer. As concerns possibilities, flexibility and efficiency, the main advancements that have been realised over the years follow from adequately integrating different production methods and tools in a more efficient and more intelligent way. Simultaneously, quite some vulnerabilities and pitfalls within production environments have been identified. More often than not, such inadequacies are directly related more to the preparatory processes than to the production processes themselves. This stresses the need for close cooperation between the design, process planning and manufacturing departments. Such cooperation concurrently aims at early assessment of design decisions as well as at bringing manufacturing knowledge and abilities to the design stage [2].

Interestingly enough, the way in which virtual reality (VR) equipment is used today shows meaningful similarities to how manufacturing systems have been organised over time. Within the scope of this publication, VR equipment is defined as tools which (help) creating an artificial reproduction of a potential reality or use condition that enables users to experience and/or modify and/or to interact with it. The changes in the possibilities of VR tools in recent years exhibit similarities to the evolvements of manufacturing environments.

For example the developments in reconfigurable manufacturing systems [3, 4] can be compared to how several VR tools can be combined in a specific cluster to work towards a pre-defined end result, and allow for opportunities not possible with a single tool. At the same time, this implementation of several VR tools within a single process is still in its infancy, and the consequences of adaption in existing design methods is not predictable enough.

There is no such thing as a standard production environment, but similarities can be distinguished and common processes can be applied to many production environments. In general, the combination of different production stations in a shared environment can be seen as a production facility. The combination and arrangement of equipment determines the possibilities within the facility. The production planning determines the scheduled routing, in which each station has its own specifications and possibilities to perform (a) specific step(s) in the production process.

The different parts that together form a manufacturing process or are related to the function and control, can be described based on a large number of terms. The establishment of these terms is mainly based on the functional specification of the tool and the description needed by the designer. Partly thanks to this terminology, it is possible to specify any production process using the same set of terms. This enables developers to communicate about production facilities in an organised matter. The terminology visualized in figure 1 is relevant in this comparison of processes.

Compared to manufacturing, for the use of virtual reality equipment there is even less a standard environment, due to the broad scope of available tools, and the non-generic origin of most tools. But also the ignorance of the available possibilities of VR for the developer and the lack of standardized methods for combining equipment. The same as with manufacturing processes, not only the hardware is relevant, but also the software and control possibilities by the user have to fit the desired method. And can therefore require some specific preparation or adaptation to fit the solution.

In the vast majority of VR environments, the use of the available tools is exactly defined by the manufacturer, and the tools provide only benefit for a limited number of potential scenarios. Originating from the development of single and stand-alone tool, which is not directly related to other available equipment, the manufacturer proposed an, at that moment and situation ideal, working method. In the reasoning for purchasing the equipment this working method is the only available integration example to base the decision on. Integrating a tool this way has the consequence that the pre-defined working method is implemented without any adjustment, and if the integration succeeds there is no need or willingness to explore further possibilities.

The same was visible within manufacturing, where in the first half of the twentieth century rigid production machinery was only used to fulfil one specific task. The machinery was designed to acquire the highest efficiency based on performing a single task, and combining multiple machines was needed to integrate multiple production steps in a manufacturing process. This is in great contrast to modern (flexible) production environments, where each machine can be programmed to perform a large selection of tasks [5].

For the comparison of a VR environment with a manufacturing environment, this article is based on the configuration and use of the VR-lab at the University of Twente [6]. The construction

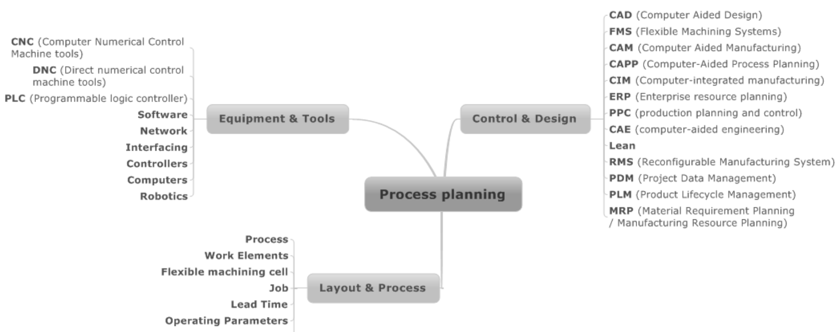

Fig. 1 Terminology in manufacturing

and use of this lab and its equipment is based on flexibility and modularity, and is treated and operated as a workshop. But even more similarities to a production environment can be highlighted.
A comparison can be drawn between a job shop [7] and the way this VR environment can be handled. Some resemblances can be resolved which can indicate similarities. First both are (single) environments in which a collection of devices enables a specific process. In addition, the possibilities are directly related to its composition, and possibly even positioning, of the tools. This configuration directly dependents on the schedule and the strategy of use; the desired end result dictates the sequence in which the tools should operate [8]. Planning this sequence is based on a translation and breakdown of each part of the product into possible manufacturing methods. Within process planning, the reliability is greatly improved over the years by implementing a better translation of product requirements to machine capabilities. Automated transition from design to process planning have also contributed to this [9]. The risk of automating transition processes is that any choice in the design can directly affect the production. Thus it may be that a designer underestimated the impact of a design choice as there is theoretically more possible than the available or existing environment can offer. Unnecessary costs can be made as too accurate and literal translations from design to product are made, and new tools may be required for a design detail which is not accounted for such an investment. This occurs most often with parts of a product which doesn't have an important role in the usage or design. For example the shape of an internal ventilation hole inside the product. This shape is not related the use or the visual shape of the product, so the designer can only provide a functional specification for it (in terms of area for example). But during the drawings of the CAD files the designer has to make the decision of the shape, although it should be completely dependent on what the easiest and cheapest option is based on the production line of the future product (which is not determined yet).
Not only in terms of specifications and reasoning, comparisons between the VR-lab and production are allowed to be drawn. Also the layout can be considered as a production environment. In the lab, the structure and configuration of the tools is not bound to a fixed setting. Depending on the wishes and demands of the user at a specific moment the tools can perform a proposed task in a certain order. In this setting the different parts of the lab directly relate to the terminology and configuration of a factory layout or job shop (figure 2). Each process in the VR-lab consists of a number of tools which together allow for use in multiple purposes. The combination and configuration of these individual tools, or the complete process can be changed with little effort. This implies that the use of a specific process (and tool) can be adjusted to the need of the user at that moment.
The terminology used in manufacturing processes is mainly based on functional specifications of a process, or to describe the process of realizing a product. Therefore it can also be possible to use this terminology for VR equipment. The goal of both environments is in fact the same; realizing the ideas of the developers and designers.
Based on all above mentioned aspects, comparing the evolvement of VR with the developments already made within the manufacturing industry can be seen as the most plausible one.

3. Evolvement in manufacturing and VR

In order to create a chronological overview of the developments within production processes, the available terminology can be placed at the time when the term originated on a timeline of the last century, see figure 3. Next to this timeline of manufacturing terminology, the same timeline of VR can be placed. With use of this overview relations can be drawn between different occurrences. It is visible that developments in VR can be related to what already has been found in manufacturing, with of course a delay of some decennia. The sequence of origin of some processes can sometimes even be directly compared, for example the transition of craftsmanship to assembly line to flexible manufacturing. This sequence of processes is also visible in the

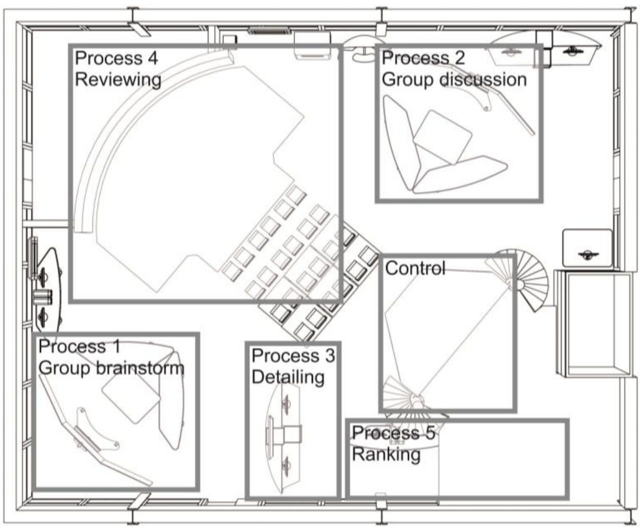

Fig. 2 The VR-lab as a factory layout

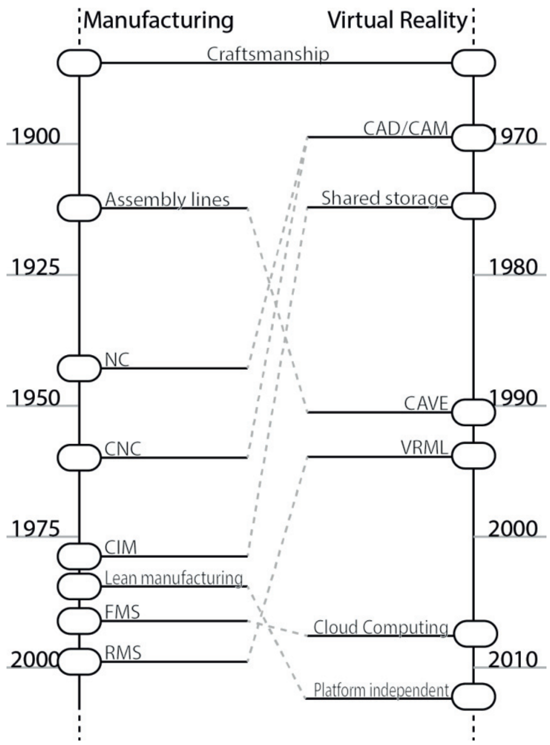

Fig. 3 Timeline of Manufacturing and VR

VR industry; from craftsmanship to CAVE to Cloud Computing.

Comparing the past and current use of manufacturing systems with the way how VR is used nowadays, some remarkable similarities come to light. Starting with the combination of different separate tools which are dedicated to a specific task.

In the early twentieth century the production possibilities and the quality of products was highly dependent on the skill of the employee, only a craftsmen was able to make complex products, and often the craftsmen was also the designer of the product (design while manufacturing). In VR the same was visible with the first available computer supported tools for designers. Only experts knew how to use it, and the use of the tool often had large consequences for the design [10]. In this situation the computer expert can become an important stakeholder in the design and development process, which could also mean that the designer has an additional translation step in the development process.

With the introduction of new automated machinery, the physical labour became lighter, but the use of the machines still required the necessary expertise. Due to the introduction of machines made to perform only one specific type of task it became possible to use lower skilled people to operate the machinery, while production numbers increased and the production costs lowered. Also, the quality of the delivered products became higher, more predictable and more consistent. As a consequence the flexibility of the tools greatly decreased, and there was little variation possible in the produced products.

A similar event happened with the use of VR in development processes. By more affordable powerful computers, the implementation of such equipment became more realistic. The possibility arose to automate specific actions using special software (e.g. CAD software). And as a result, it was useful to integrate specially designed VR hardware in some development processes to achieve the same benefits as with the automated machinery. The drawback of this integration was that the available hardware and software also brought new limits and boundary conditions to the designer, resulting in adjusting the design to the capabilities of the computer systems. For example the available CAD/CAM software was sometimes more limited in drawing capabilities compared to what the production machines could perform.

Because of this transition into a rigid mechanization process, the production costs lowered and made it possible to fabricate products for a larger group of people. Adjusting each individual product to the wishes of the customer was at that moment not possible. The diversity of producible products was thereby very limited because the design was adapted to the possibilities of the functions of the available tools. And even those available tools had to be adjusted to the specific product being produced at that moment; specific parts of the machines had to be fabricated or changed if another product has to be produced. So not only the product itself had to be designed, but also the necessary tools needed to be able to produce the product using an automated process with unskilled people. Most designs had to be adjusted to these rules and limitations to fit to the available knowledge and equipment.

Within the use of VR a similar event occurred when for example the first motion capturing tools became available. These specific tools made it possible to capture the movement of people in a pre-defined and limited (in size and location) environment. Because of these limitations not all aspects of a design could be tested using VR, and the emphasis was on the testable aspects. Because only parts of a product could be tested, the assumption was often made that test results of individual parts were also valid in the complete design (which is not always true).

The development of more generic tools that could perform a wide variety of actions, without too drastic adjustments, made it possible to allow designers and developers more variety in design. The transition into flexible production environments [11] led to a major change in the development process. With the use of autonomous systems the conversion from design to production can be done easier and faster [12]. This all led to a shortened development time. As a result, it is often unclear for the designer what process is responsible for each stage of production. Consequently, the designer has less control over the method of production, and thus is less able to possibly implement improvements in the product that will lead to production benefits. These production environments seem extremely flexible, but in practice they offer just more rigid borders in which the designer has to manoeuvre within. And only within these borders the designer has more freedom during the design and development phase. A similar effect is visible when new (VR) equipment is added to an existing method, without making clear connections with the input and output of other project phases. The risk occurs that VR equipment is handled as a separate process within the development stages, and that the flexibility is limited within the boundaries of that specific tool. The output of the tool has to fit the input of the next phase, so without the adjustment of adjoining process not more flexible is offered.

No extremely different approaches or designs are possible in the preconditions of this setting, and a kind of pseudo-flexibility is created. The result may be that the specifications of the borders defined within the available production processes are more important than the conditions and functionality of the final product.
In the pursuit for a lean production environment [13], flexibility alone is not enough. Within a flexible environment there are always elements of a process or machine which are not used at a specific moment. In a lean production environment there should be an optimization of product and process; both should be adjusted to each other, and only the necessary tools, resources and techniques should be available. The possibility to adjust the production process to fit the produced product is essential. This adaption creates a most optimal way of producing, in which only the tools needed are available and are used, or could be reused at another site [14].
The aim for a lean environment in VR is something which is still in an early phase, this is mainly due to future perspective of the usage of equipment. Within the manufacturing equipment, a (stand-alone) tool will function the same over the years as long as the supplied material is the same. Within VR the equipment often makes use of digital data created by other devices. This dependency has the consequence that with future software updates a compatibility can be lost. Often this can be fixed by software updates, which can require higher hardware specifications due to new functionality. Therefore the equipment is often over-specified at the implementation phase. The first clear signs of a lean VR environment were recognizable in the use of terminal clients, which all utilize the capacity of a shared centralized server. In this situation the server can be used at its most efficient workload all the time, spread over a best fitting number of clients [15].

4. The practicability of this comparison

In order to make optimal use of the possibilities of VR, it is at this time necessary to have expertise available for each different step and tool in the process. Current virtual reality equipment still requires a high level of craftsmanship to achieve the maximum results possible with the equipment. What the maximum result can be also depends on the desired goal of the current user, and what the expectations are. The same was true to production processes for a long time. Examining and comparing how the research and development in the field of process planning made the translation of a rigid environment to a reconfigurable manufacturing can be used to prevent fallen into the same pitfalls with VR. By making use of existing and experienced systems from the production industry into VR allows for a better integration of VR in the whole production chain. This integration is improved by allowing the designer to use the best fitting tool for his purpose [16], without the consideration if it should be a virtual or a mechanical process.
An example of a comparison between VR equipment and manufacturing process is a VR CAVE setup [17]. A CAVE can be compared to the first assembly line, introduced by Henry Ford in 1913. The assembly line is very consistent and efficient in producing one type of product. As long as each product on the line is exactly the same, there is a maximum efficiency achievable with the available combination of tools. In case a product which deviates from the standard specifications has to be made, a lot of money, time and energy has to be invested in the line. The same can be said of a CAVE, which is also an environment specifically intended for performing a predetermined process. A CAVE is flexible in the presented data and content, but the use possibilities are confined due to some very strict limitation, such as physical size, number of participants and location. To use the tool a lot of preparation is needed made by others than the intended user, and during the use experts should be available to support the process, but for using the tools there is no expertise necessary. This results in quite limited possibilities for the use of a CAVE. Due to the high investment costs it is also difficult to justify such an investment for only one process. This can lead to a tool that is more or less obliged to use in order to justify the investment.
Just as in manufacturing, new developments in VR offer new tools and techniques to improve, simplify or facilitate a certain part of the workload. Nevertheless, these developments often will not change the development process. This implies that only the content and execution of a single or multiple development phase will change, but that the overall steps in the whole process remain the same. This is partly due to the fact that the development of many new tools is based on the current used methodology, while there might be greater profit achieve by adapting to whole process to the new technologies.
Due to the major risks associated with adjusting a complete development process, there are few innovations that address this whole process. By reviewing at how the combination of several innovations in manufacturing led to a completely new process over the years, some uncertainties in the development of VR can be removed [18].
A designer often has the goal to design a product which has the least commitments in it; “Design by least commitment” [19, 20]. This creates more freedom in the way of producing the product. And as a result it will become more important to clearly define the main functional requirements and specifications of (parts of) the product, instead of the production process. By documenting this clearly it is possible to define the final product as a ‘solution’. These solutions are enabled and created using a combination of ‘tools’, which are built from multiple techniques [21].
In the use of the VR-lab, the available tools are known on beforehand, but the layout is flexible. In addition, the modular environment offers the possibility to set up an alternative machine for each tool or technique. This allows for changing tools and techniques (which are part of the solution), without visible or noticeable consequences for the final product. This way the production preparation is directly related and derived from the design.
To stimulate and facilitate this flexible and reconfigurable integration of VR tools, without a lot of preparation time, a real-time conversion from functional specification to practical implementation is needed. The knowledge already available in the manufacturing industry can help speed up this process. Translating the fundamental way of thinking of these developments to how it should be applied on VR equipment offers a good starting point on creating an environment of virtual solutions which adopts in real-time to the preferred goal of the actual user [22].

5. Conclusions

In the comparison of product development innovations over the last century to the current use of VR equipment in development process, some similarities come to light which have potential to improve the quality of the implementation of new VR equipment in terms of predictability, preventing pitfalls and linkage with the producibility of the product.

By approaching the use of VR (equipment) in product development processes the same way as the integration of the production process, some advantages can be achieved. For example the best practices experienced in developments of production can be translated to how that will influence the use of new VR tools. In addition, the possible pitfalls can be bypassed through solving the reasoning behind the different phases of manufacturing. Furthermore by analysing and comparing the best practices in manufacturing developments, certain developments in VR could speed put by omitting steps which failed in manufacturing.

From the process planning additional indications can be resolved which can be used in the future vision of the use of VR. Especially in the flexible and fast integration of multiple tools with dependencies a lot of developments are already available in the manufacturing industry. It can also give insight into the possible effects of implementing new techniques on beforehand. For this it is important to discover similar steps already made in manufacturing. This can lower the threshold for using new technology, and could improve the justification of certain investments.

Another, not be underestimated, possibility and advantage with the comparison is to prepare and anticipate on major alterations. These changes are not always predictable, but with the current high speed of tool development it is a necessity to respond quickly to this occurrences. Especially within VR continuously new technology becomes available whose usefulness and integration within design processes is not obvious at the moment of introduction. Drawing a comparison between how the manufacturing industry handled, for example, the introduction of plastics can possibly predict what the impact of new technologies could be. At first, the introduction of plastics resulted in products which could be properly made easier into a mass product (e.g. injection moulding). Only after several decades the same material brought the ability to allow for extreme customized to the needs of the customer (e.g. 3D printing). These consequences remain unpredictable, but provide insight and consciousness in the broad scope of affects. Further research will be done to concretize the necessary steps needed to utilize the comparison, and to examine the relation with, among other things, Industrial Product-Service System (IPS²).

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