# RAPID PROTOTYPING – DEFINITION OF TERMS AND HOW TO APPLY DURING A STUDENT PROJECT

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***Abstract:*** *Nowadays the field of Rapid Prototyping is rapidly changing and providing a clear overview is challenging. One of the biggest problems in this context is that different operations are often named similar. In the beginning of this paper the most important related terms are defined and classified. Afterwards the major Rapid Prototyping techniques, called generative manufacturing methods, are explained. Alternatives to these generative methods as well as 3D-scanning methods are dealt with too. All in all these emerging technologies around 3D-printing and 3D-scanning are revolutionizing the way Rapid Prototyping laboratories look like. They offer new possibilities and reduce the complexity of prototyping. One of the future trends is so called Fab Labs which are currently stretching the boundaries of the common Rapid Prototyping laboratories. At Graz University of Technology the second Fab Lab in Austria has been established lately. Especially its implementation in University education as part of the Product Innovation Project is discussed in detail.*

**Keywords**: RAPID PROTOTYPING, 3D-PRINTING, 3D-SCANNING, GENERATIVE METHODS, STEREOLITHOGRAPHY, GENERATIVE SINTERING, FUSED DEPOSITION MODELING, FABRICATION LABORATORY, PRODUCT INNOVATION PROJECT, FAB LAB MOVEMENT

## *1. Introduction*

As the field of Rapid Prototyping has been growing quickly during the past few years, several definitions for Rapid Prototyping are known. Also the term of 3D-printing is often used across the board and is seldom clearly defined. If one takes a closer look at the field, these circumstances increase the risk of confusion. Especially the use of the term 3D-printing as an umbrella term is crucial in this regard. Therefore as a precaution the most important terms of the field are defined and classified before going deeper into the topic. Besides the major generative and conventional Rapid Prototyping methods, which are the essential basic tools in prototyping, are presented.

Connected to the quick advancement of Rapid Prototyping possibilities is also the so called Fab Lab movement. Its main ambition is to simplify prototyping and enable more and more people all over the world the possibility to manufacture their individual items themselves. The worldwide exchange of prototyping and manufacturing knowledge is only one benefit that is generated when being part of the network. As there exists a course called “Product Innovation Project” at Graz University of Technology, which deals with the development of prototypes, the establishment of a new Fab Lab made perfect sense.

In the second part of this paper the Fab Lab movement, the new Fab Lab in Graz and its application within the “Product Innovation Project” course will be described in detail.

## *2. Rapid Prototyping*

The term Rapid Prototyping stands for an application of the generative manufacturing methods. These methods are based on the layering principle, which implies that an object is made up of plenty of thin layers. [1] In numerous steps the layers of material are added onto each other and an energy source ensures that they get adhered and hardened. The layer material can either be in powder form, fluid or in hard condition. The major advantage of these methods compared to conventional ones is that there are hardly constraints concerning the shape of the desired object. [2]

Beside other applications like Rapid Tooling, which stands for the fabrication of moulds, tools and equipment for production processes, Rapid Prototyping is defined as the fabrication of models and prototypes without product character. When custom-specific final products are produced in individual or small series the application is called Rapid Manufacturing. On the contrary Additive Manufacturing describes the application of generative methods in case of serial production. [1]

According to VDI guideline 3404 nine generative manufacturing methods can be distinguished in total: [3]

- Stereolithography
- Laser sintering and electron beam melting
- Fused layer modeling (Fused deposition modeling)
- Multi-Jet modeling
- Poly-Jet modeling
- 3D-Printing
- Layer Laminated Manufacturing
- Mask sintering
- Digital light processing

A description of each method would go beyond the scope of this paper. Therefore the focus is on the three major ones, which are stereolithography, laser sintering / electron beam melting and fused layer modeling (fused deposition modeling). [3]

The company “3D System” introduced Stereolithography in 1987. It is known as the oldest generative manufacturing method. [3] The principle of stereolithography is the layer by layer solidification of fluid or pasty monomers through polymerization. Within the group of stereolithography several different sub-methods can be distinguished. Whereof the laser-scanner-stereolithography can be seen as the prime father in case of industrial used rapid prototyping processes. [4] The necessity of supporting structures and the poor thermal and mechanical resilience of the objects produced are offset by the high level of detail and the achievable refinement of their surface. [5]

In the early 1990s the generative sintering was known as laser sintering due to the fact that all common systems used a laser as energy source. Nowadays machines using an electron beam or infrared radiator for the fusion and solidification of the layers are frequently used too. The basic raw materials are densely packed and precompressed powder particles out of metal, ceramic or resin-bonded sand. These particles get fused by the energy source and so layer by layer the object is built up. [6] Although there are basically no supporting structures needed because of the supporting effect of the solid raw material, however they are often used to ensure a good heat dissipation to prevent warping of the metal material. [7] Temperature control is crucial because already small deviation can lead to poor sintered or discolored useless objects. [8]

The company Stratasys introduced the fused layer modeling or fused deposition modeling method. In most of the applications ABS or PLA plastic filaments are used as basic raw material. By passing a heated nozzle the temperature of the filament rises close to the melting point of its material. Once the filament is pasty it's deposited onto the previous layer. Through heat conduction the material cools down, fuses with the prior layer and hardens immediately afterwards. Although the surface quality is often quite poor and overhanging sections of the objects require supporting structure, the method is quite popular because of its low costs and office suitability. [9]

Another generative method is called 3D-printing. Although it only represents one of the nine generative manufacturing methods, it is more and more used as an umbrella term for all of them. Obviously this can easily cause confusion. Therefore it is essential to use the correct terms while working professionally in this field. [10]

After all prototyping doesn't necessarily have to be done by using one of the named generative methods. There are also possibilities to build up prototypes with conventional manufacturing techniques like a CNC-milling or laser cutting. [11] While laser cutting is suitable for building up prototypes out of piled thin layers and is commonly used in architecture, prototyping with CNC-milling can be very challenging especially if the structure of the desired object is complex. The achievable excellent accuracy is offset by the constraints regarding the accessibility of narrow and angled areas of the object. Clever combinations of generative and cutting processes offer great potential. Through using the generative manufacturing methods to build the object there are hardly limitations regarding the shape of the object. Refining it afterwards by using cutting methods, enables the achievement of excellent accuracy and surface quality. [12]

Prototyping with all of these methods requires a 3D-CAD-model as a starting point. This can either be designed by using common CAD-software or, if the object already exists, it can be scanned through using a 3D-scanner. The technology of 3D-scanning is advancing rapidly in the past few years. Beside applications in different fields like medicine, historic preservation or the packaging industry, it is also widely used for quality assurance and digital archiving of prototypes. [13] Especially the technology of desktop-3D-scanning is emerging hand in hand with office suitable 3D-printers.

Basically contact and non-contact 3D-scanning methods can be distinguished. As in desktop-3D-scanning the disadvantages like the high costs, the low speed and big effort of the contact based methods outweigh the achievable accuracy of the scans, the focus is on non-contact methods. The most common methods used in desktop-3D-scanning are triangulation-based laser-scanning, structured light technology and photogrammetry.

At the moment the uprising competition among these 3D-scanner devices has been pushing down the prices to a few hundred Euros. It is very difficult to maintain the overview of the market as there are new solutions brought to the market frequently. One of the latest trends is the combination of these desktop-3D-scanners and the already above mentioned 3D-printers in one device.

These emerging technologies around 3D-printing and 3D-scanning for home users are revolutionizing the way Rapid Prototyping laboratories look like. They offer new possibilities and are reducing the effort to build a complexity prototype. One future trend of these Rapid Prototyping laboratories, also called maker spaces, is a Fab Lab.

## *3. Fab Lab – A Maker Space*

The first Fab Lab was set up by Neil Gershenfeld at the MediaLab of the Massachusetts Institute of Technology (MIT) in 2002. The acronym Fab Lab stands for Fabrication Laboratory. The basic idea of these labs is to provide individuals access to manufacturing tools, so that they are able to produce their own things. As long as commercial activities of the users do not interfere with the access of others, they are tolerated. [14]

There are four main criteria that have to be fulfilled to start a Fab Lab. First of all the lab should be accessible free of charge for everyone at least once a week. Secondly the Fab Charter, which states the principles of the Fab Lab movement, has to be published on site and on the web page of the lab. Furthermore all labs should be equipped with the same basic tools to ensure the exchangeability of designs, knowledge and the reproducibility across borders. In addition the support of other labs and a contribution to the Fab Lab community is expected. [15]

Nowadays the Fab Lab movement is spreading rapidly all over the world and currently there are already more than 330 Fab Labs registered. [15] At the Institute of Production Science and Management of Graz University of Technology the second Fab Lab in Austria has been built up in the last few months. The equipment had been well chosen according to the guidelines of the MIT. These already mentioned common equipment includes a computer-controlled laser cutter, a plotter cutter, several programming tools, a precision milling machine and also a numerically-controlled milling machine. [16] Although there are a lot of commonalities among the different Fab Labs, every lab still has its own identity. Slight differences regarding the services and tools which are provided in the labs and the various user groups determine these identities.

Based on our own experience an extension of the provided tools towards a 3D-printer makes the most sense. Therefore at the Fab Lab at the Institute of PSM additionally a 3D-printer named "3D Touch" is available. Furthermore the required basic tools as a MDX-540 SA precision milling machine from Roland, a CAMM-1 Servo GX-24 plotter cutter from Roland and a VLS 3.50 laser cutter from Universal Laser Systems are provided. Although there is only limited space, additionally a sand blaster, a computer workstation, a workbench and some electrical tools are available. Basically the lab can be used by all students of the University and once a week also by external visitors. The main target group consists of students who are participating the course "Product Innovation Project".

## *4. Rapid Prototyping in University Education – The Product Innovation Project*

The course "Product Innovation Project" was founded in 2006. The main idea is to bring students of different fields of study together to work on projects and develop new products. The students have to work as a team to be able to create a solution to fulfill complex product development tasks. The outputs of the course are working prototypes. Key elements of organizational framework of "Product Innovation Project" are interdisciplinary, intercultural and international student teams. It shall impart the holistic view on the product development process, from idea generation until the market introduction. An adequate budget – paid by the industrial partners – allows the manufacturing of a working prototype in workshops like a maker space.

"Product Innovation Project" splits up the innovation process in a way that the process steps are carried out by different executing parties according to their strengths and weaknesses. Whereas university acts as a host for the project preparation, organization and contributes its specific technical know-how and facilities, the main actors in the actual innovation process are the student teams. The industrial partners cover the very first (the strategic decision of "what and how to innovate") as well as the very last phase in the process (refinement, production, and market introduction). The teams of students intermediate carry out the phases from idea generation until the preparation of a working prototype and a product concept, as seen in Fig. 1. [17]

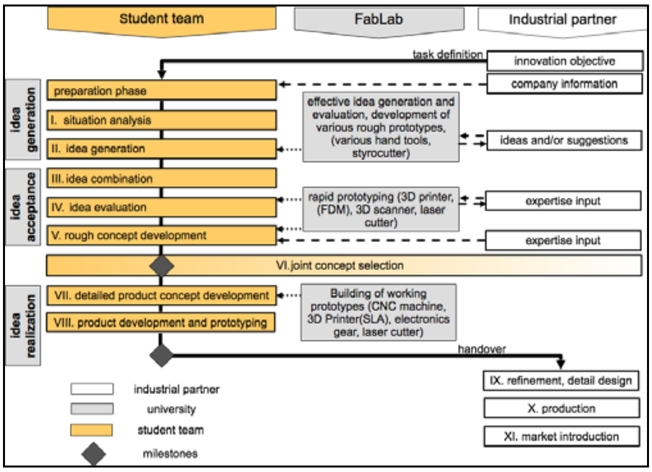


***Fig. 1*** *Integration of "Product Innovation Project" into the innovation process according to [17]*

In past periods of the project, it was recognizable that in addition to support provided by the industrial partners, the student teams are willing to make various different prototypes on their own instead of hiring a contract manufacturer. But this was not possible due to an inexistent small fabrication laboratory. While analyzing the product development process, it's worth noting that it is not only necessary to have maker equipment in phase VII and VIII, where the students put all effort on the development and realization of the working prototypes. Especially in the phase II, IV and V a fast and uncomplicated access to manufacturing machines is essential. Students can generate far more ideas or rough product concepts when virtual 3D models are transformed in physically existing prototypes. Experience shows that often only these prototypes allow proper evaluation of product size, materials and other important product attributes. Early prototyping as well as detailed research on the available solutions, their advantages and possible problems, their stage of maturity (research stage or available on the market) are the basis for an outstanding result and a small fabrication laboratory provides the right tools.

In addition, cooperation between the stakeholder groups can provide benefits for each of them, like hands on experience for students in a product development project, additional funding and research fields for universities or access to qualified students for companies. These benefits are the result of an up-to-date learning environment, involving students, industrial partners and scientific staff of universities. It is worth to mention that students are investing the most working hours compared to other stakeholders in such a project. Due to this reason, the members of the student teams play a key role within the stakeholder constellation and it's very important not only to ensure their motivation but also provide them professional facilities to support the product development process.

## *5. Conclusion*

The past few years showed what students are able to create, if they got the chance to develop their own projects. Students learn through challenges, so it's important that the university challenge their students. In addition, the idea of having a physical output is a long-term motivation for every student. Due to this reason, Graz University of Technology decided to go one step further and join the Fab Lab community in summer 2014. Through providing such an environment, where students can make their ideas real, it can be ensured that they have the possibility to develop their full potential.

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