

Protection measures against product piracy and application by the use of AM

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Abstract

Presently the implications Additive Manufacturing (AM) on intellectual properties are discussed in public. Here AM is often mentioned as a driver for product piracy as it allows to produce and to copy objects with any geometries. Imitators need a lot of information to copy an object accurately. As reverse engineering has been identified as the most important information source for product imitators, AM can also help to reduce the threat of product piracy when correctly applied in the product development. Due to the layer wise production process that allows the manufacturing of very complex shapes and geometries, the reverse-engineering process can be complicated by far. By this, quite contrary to the public opinion, AM can increase the needed effort of imitators and strongly reduce the economic efficiency of product piracy. This paper will show different protection measures and a methodological approach of how to apply these measures to a product. Beside the protective effect some measures allow a traceability of parts over the product's lifecycle and thus support the quality management of AM processes and additively produced parts.

Introduction

Product piracy is already referred to be the crime of the 21th century by Manfred Gentz (president of the international chamber of commerce). In a study of the German mechanical and plant engineering industry its impact has been estimated and is quiet enormous. In 2013 economical losses of € 7.9 billion relating to a total turnover of € 205.8 billion have been determined. The same studies show how the affected companies try to act against this threat. Most of them still feel secured by registering industrial property rights, careful selection of partnerships and by keeping internal know-how a secret. Only 38% of the included companies decided for a technical protection of products. [VDMA14] Having a look at how imitators gather the required information for copying products the companies cannot be successful with their strategies. Reverse engineering has been identified as the most important information source of the imitators. Compared to industrial spying with 15% relevance reverse engineering is applied in 72% as data source for imitations. Therefore companies should rethink their approaches and try to stay more preventive than reactive. [VDMA14] Technical protection complicates already the reverse engineering while legal measures become effective when a product has already been copied physically.

In public media Additive Manufacturing (AM) is often stated out as a driver for product piracy. This is mostly explained by its capability in combination with scanning technologies to copy 3-dimensional objects just by pushing the button. But also scanning technology may be a part of reverse engineering. Therefore this paper will not discuss whether AM is usable for everyone or only for experts but it will take the reverse engineering into account to understand what imitators are doing. Based on this analysis an approach for development of protective measures using AM to complicate the reverse engineering will be stated out. Finally this paper is supposed to show a five step methodology as a guideline to implement protection measures in products to be (re-)developed. It is based on results of the project

“3P - Prevention of Product Piracy” carried out in the technology network “intelligent technical systems” OstWestfalenLippe (it’s OWL) with 174 collaborating industrial partners and research institutes.

Beside protection against product piracy in a preventive way by complication of reverse engineering the potential of AM in terms of individualization of parts without increasing costs [Zaeh06] allow individual markings to be integrated in parts as well. Thus some of the measures developed can be used to achieve a traceability of parts during the whole product lifecycle. In some branches as for instance in medical applications traceability of parts is mandatory by law. For other industries threatened by product piracy the determination of original and imitation is very important. In event of a parts’ failure its definite authentication might save costs due to unjustified product liability. A study commissioned by the UK by Intellectual Property Office reported traceability of parts as one major requirement for broadening the use of AM even in industries that are not focusing on product with critical functionality. [ReMe15] It is essential for quality management and continuous improvement of product and processes to be able to trace back from a physical object to its production process, parameters, responsibilities etc.

Reverse Engineering

To imitate a product know-how of the product to be copied is needed. If it is not existent the reverse engineering is a way to gather and analyze all the information for (re-)production and distribution. [Ingl94] [Wang11] [OtWo01] In literature the process to reverse engineer a product is defined not clearly as there are different approaches to start. All these approaches basically aim at gathering the same information but in a varied order. In this paper the reverse engineering process is defined as a combination of the procedures mentioned in literature. It is divided in eight phases that are not necessarily sequent but partly parallel (see *figure 1*). In addition to the process steps discussed in literature one more activity has been integrated for assessing costs directly during the process.

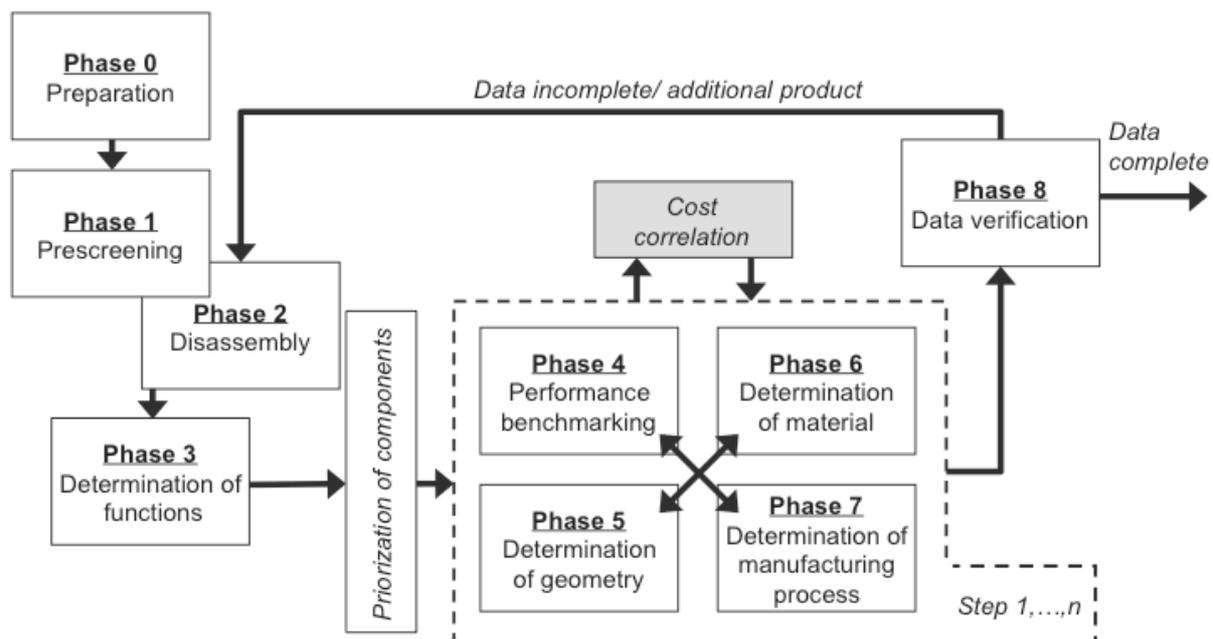


figure 1: Reverse Engineering Process

In the following the activities and contents of each process step are described to achieve a common understanding of the activities and effort that imitators need to wage. The knowledge

about this process is very important as it is the basis for development of measures that complicate the reverse engineering and thus contribute to a prevention of product piracy.

Phase 0: Preparation

The product to be reverse engineered is selected and the efforts in terms of resources, temporal conditions and costs are estimated. Determination of needed knowledge as well as the calculation of margins and return on investment is taken into account in this stage. Original manufacturers should reconsider available data from web or data sheets. This includes a legal review (patents or property rights) as well. All this information contributes to a good preparation of imitators.

Phase 1: Prescreening

The prescreening is mainly focused on a first inspection and usage of the product in a full range in terms of a full function test (using the product by switching and testing for example all possible input parameters). In parallel assumptions on functions, geometry, performance and material are documented.

Phase 2: Disassembly

Original manufacturers can complicate this phase avoiding non-destructive disassembly. Thus it will be harder to achieve the main aim to split up the whole product in separate components to document the bill of materials with properties for the single parts (quantity of components, material, color, surface etc.). Furthermore a cost-breakdown estimation becomes more difficult right now focusing not only on costs of components itself but also on effort and needed time for design and production planning for each component.

Phase 3: Determination of the functions

Determination of the functions is an important step for understanding the product and its principles in detail. Original equipment manufacturers (OEM) can concentrate on hindering the Analysis of the product by functions and functional diagrams and a classification of main and sub functions envisaged by reverse engineers. To prioritize the components for the following steps it is necessary to assess which parts are essential to ensure the product's main functionality. This is difficult to do without decoding the functionality.

Cost Correlation (in parallel during phase 4 to phase 7)

Additionally to the phases shown in the literature a cost calculation is considered in parallel to phases four to seven. To achieve a protection it is necessary to make the product appear unattractive. From economical point of view the effort to produce an optimal imitation has to seem tremendously. If product characteristics can be determined by potential imitators, which can be implemented only by high investments, they need to decide whether their return of investment is threatened. Hopefully they assess this as hardly reachable and stop the entire reverse engineering process not to spend more effort for unprofitable or even unreachable results.

Phase 4: Performance benchmarking

For copying just the appearance of a product as it is made for counterfeits of valuable brands with a good reputation, this step is irrelevant. Otherwise performance benchmarking is essential for estimating the potential of the product and to setup a reference to be able to compare the performance of the imitation. The less successful the product's analysis in previous steps is the more time consuming is this phase. There are different relevant techniques to use for the benchmarking:

Cost Benchmarking for detailed cost comparison [SAT05]

House of Quality to analyze the relation of requirements and technical characteristics [GUI11]
Comparison to competitors in terms of market shares etc. [OTT01]

Phase 5: Determination of geometry

The geometry of the product needs to be determined from physical to digital. 3D scanner or similar scanning techniques might help for simple structures. Manual measurement and design effort has to be considered for shapes that are hardly scannable. OEMs achieve a prevention designing complex geometries and dimensions difficult to measure. Tolerances have to be determined by answering the question “How much can the measurement deviate from the nominal size, without having influences on the function of the product?”. [DUB97]

Phase 6: Determination of material

Material tests and determinations can cause high costs and have to be appropriate for the concerning goal. Laboratory tests are more accurate than quick tests and required for a perfect imitation. Manufacturers can focus on specific materials necessary for a function as imitators try to find materials that achieve the same performance than trying to duplicate the original material. But for a material change the following aspects have to be taken into account:

Legal obligations, common law, technical standards and safety rules

Risk assessment for missing performances

Significance of the material for the functions and performance

Phase 7: Determination of manufacturing process

Know-how and experience in manufacturing methods are necessary for a reliable determination. Supporting information can be derived from market environment, manufacturing locations and envisaged lot size [GUI11]. Therefore a protection can be achieved by watching the spread of information of the original product. Analysis in phase 4 as well as the geometry of parts may indicate the manufacturing process.

Grid sizes, surface quality and skin layers reveals parameters of the used manufacturing methods, which can be adapted. It has to be mentioned that some treatments can modify and cover up shapes and leads to false parameters.

Phase 8: Data verification

All data previously collected and determined need to be consolidated. The integrity and accuracy of these data has to be proofed whether all gathered information is sufficient to create a successful imitation. Further tests and experiments with or without prototypes validate the product's information. Sometimes more adequate results need multiple iterations through the whole process. [WAN11]

Development of measures

To prevent the previously described reverse engineering it has to be determined which protection measures can stop the process or at least one necessary step of reverse engineering successfully by complication. These must either be selected from an already vast variety of measures or developed from scratch. For a better limitation during the selection of measures a categorization is useful.

Protection measures can occur as preventive or reactive protection measures [Nee07]. However the breakdown between prevention and reaction only defines a timeframe for the enforcement of product protection. Depending on the occurrence, protection measures can thus be applied preventively as well as reactively. A patent for example can be used on the one hand reactively to enforce legal claims against imitators and on the other hand preventively to discourage potential product pirates from further infringements.

Therefore a subdivision of prevention and reaction is not sufficient to select appropriate measures against reverse engineering for the own product.

In contrast to this, a categorization according to the appearance of protection measures provides a good subdivision. This categorization includes seven categories as shown in *figure 2*: strategic, product-related, process-related, communicative, marking, IT-based and legal measures. [Kok12]

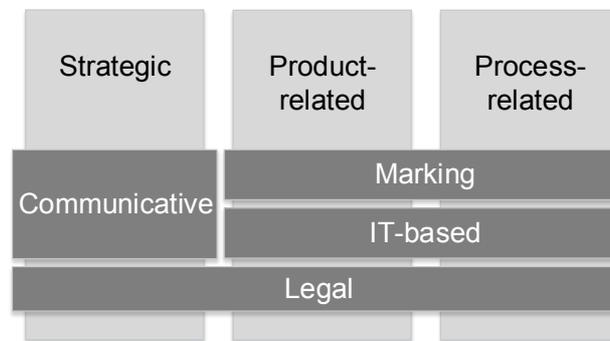


figure 2: Classification of protection measures acc. to [KOK12]

Of these, product-related and marking measures can be used to prevent reverse engineering as described in the following. Marking protection measures are used to provide original products or packaging with a label. They should allow to detect originals and imitations reliably and thus to classify products correctly. Hereby customers can be protected from unknowing acquisition or use of an imitation and original manufacturers can be supported in the event of a dispute in the evidence [Gün10]. Further more information can be saved by using a label, so marking measures can, in addition to the protection of the product, also support the traceability. There are mainly two kinds of marking measures to be distinguished: measures, which are visible and therefore noticeable by the customer directly, and measures, that are hidden or concealed to make it difficult to imitate the original. Examples for marking protection measures are two- and three-dimensional barcodes or holograms. [GGL12]

Against this product-related measures may protect either the entire product or single components directly from reverse engineering. They occur in particular as structural implementations in the product and are intended to protect products and components whose production is worth protecting know-how of the company. Examples for product-related measures are de-standardized parts or the integration of functions. [GGL12]

With the existing marking and product-related measures products can already be protected well. But AM offers potentials to increase the effect of product protection further more. These potentials base primarily on the layer-wise manufacturing of AM. Thus, highly complex structures can be manufactured, which are uneconomical or even not producible by using conventional production methods. Precisely this freedom of design makes it possible to integrate functions, which need to be assembled from multiple components by using conventional methods, into a single component and thus to aggravate the reverse engineering process. With the integration of several functions into one component, the complexity of the geometry is increased and the effort for the return of the geometry of the physical component into CAD is aggravated. [JaWi14-ol]

In order to exploit the potentials of AM a methodology has been developed at the University of Paderborn, that allows the targeted elaboration of new product protection measures (see *figure 3*).

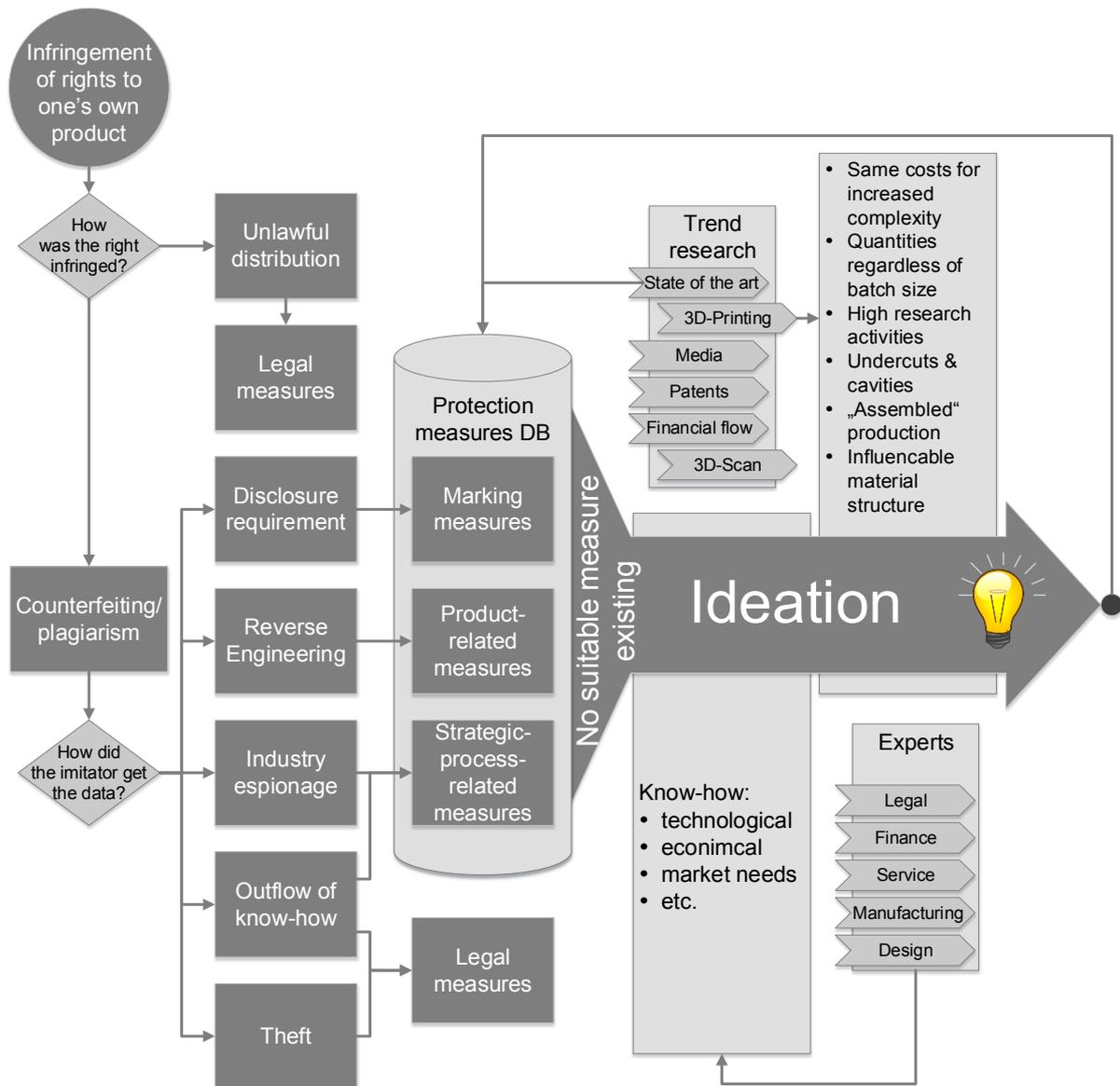


figure 3: Ideation process for development of innovative protection measures

The need for new protection measures usually arises by a previous violation of the rights on one's product. In this case it has to be determined whether product pirates have infringed the right by an unlawful distribution of one's product, for example through the sale of stolen goods, or by counterfeiting or plagiarism. Unlawful sales can generally be prevented only by legal measures, so in this case, no measures have to be specifically developed for AM.

On the other hand if there exists a counterfeiting or plagiarism, the protection measure category for the targeted development of new measures may be limited by using the ways to gather information for imitations determined by the VDMA. In addition to the already mentioned reverse engineering and industrial espionage these are outflow of know-how, disclosure requirements and theft as well as the often occurring case, that no information gathering for the imitation is necessary. Depending on the information gathering the original manufacturer can detect whether marking (No information gathering necessary, disclosure requirements), product-related (reverse engineering), strategic-process-related (industrial espionage, outflow of know-how) or legal measures (outflow of know-how, theft) are useful for the protection of the own product.

This paper will specifically refer to the prohibition of reverse engineering and the traceability of products, thus at this point the strategic-process-related measures will not be discussed further. According to a further exclusion of the legal measures (these are valid for all manufacturing methods equally) the manufacturer can resort to an already existing data base of measures. If it is not possible to extract therefrom suitable or at least slightly protective protection measures, the “ideation”-process is carried out.

Considering the potentials of AM and expert knowledge of the own company creative techniques such as brainstorming or 6-3-5 are used for the ideation in this connection.

However, both the potentials of AM and the expert knowledge are no fixed information. Since the product protection should always move at the head of the state of the art, the ongoing development of the known potential and know-how is crucial to a company’s competitiveness. For this results of trend researches have to be implemented repeatedly into the known potentials of AM. These include the consideration of the state of the art, media, patents and financial flow and should also take technologies into account which are critical for the effect of product protection measures (e.g. 3d-scanning).

Results from the ideation are innovative protection measures. On the one hand these can be applied to the regarded product and on the other hand anchored in the database of the known protection measures.

The ideation process described above has to be in mind every day as there is no way to get ideas on demand. Thus during the project “3P - Prevention of Product Piracy” 22 protection measures using the potentials of AM have been developed. For each measure there is a general description as well as a specific contribution of AM to the effectiveness collected in a catalogue. Marking measures and product related measures have been validated in cooperation with companies and on demonstration samples. One important result of this validation is the definition of requirements that come along with the protection measures. For instance external marking measures may not be applicable on a part’s surface if there are surface-depended functions like interfaces to adjacent parts. Exemplary measures that benefit a lot from the use of AM:

- Integration of functions
- Black box design hiding the main functions
- Self destructive design; effective in combination with black box design
- De-standardization / avoidance of standard dimensions
- Marking by internal structures or local modification of density/microstructure

Methodology for Application

Based on the experiences of the industrial cooperation and the specific use case brought in by companies a “five step approach” has been elaborated to get the measures into application. The core activity as well as the results of each step are shown in *figure 4*. The first three steps of this methodological approach aim at selecting the part or component of product that may be protected using AM. Following one or a combination of measures need to be selected that fit to the requirements of that component and finally the measure has to be implemented in terms of (re-)design. The single phases are described in the following.

<i>Task Description</i>	<i>Result</i>
Definition of scope: existing product or product to be developed	System analysis of product
Trade off methodology: selection of most promising parts to be manufactured additively based on system analysis	selected parts most suitable for AM
Assessment of importance of components for the functionality of envisaged product	selected part to be protected
Selection of protection measures to be applied based on the parts characteristics	selected protection measure(s)
(Re-)design of part to integrate the protection measure(s) considering requirements of the part and adjacent parts	protected part / product

figure 4: five step approach for application of protection measures

Definition of scope

This step defines the basis for the following activities. It aims at analyzing the product to determine the architecture of the product in terms of how components fit together to fulfill the product's functionality. For an existing product this step is effortless as the documentation and the bill of materials of the product can be used. For a product to be developed the first steps in the development process acc. to VDI 2221¹ need to be elaborated. At least the functionality has to be defined and divided in modules, sub-functions and components.

Trade off methodology

Here the methodology for selecting most promising parts to be manufactured additively that has been developed at the University of Paderborn will be used. Single components of the product envisaged will be checked concerning manufacturability also considering economical aspects. Criteria to be assessed for each part - number of parts, dimensions, material requirements etc. - have been defined and validated during several projects funded by the European Commission and the European Space Agency (ESA)². The option to combine several parts into one design should be considered. Therefore standardized forms for requirements engineering developed in the project funded by ESA can support this stage. [LRJ+15]

Assessment of importance

The main objective in this phase is to rate the importance of the components previously selected for fulfillment of the overall function of the product. In particular it is necessary to rate only the parts suitable for AM. Very helpful in this phase is to have the product's architecture in mind that has been analyzed in step one. For most products it is sufficient to protect just one single most relevant component to achieve a protection of the whole product.

¹ Guideline VDI 2221: "Methode for development and design of technical systems and products"
VDI: Association of German Engineers

² Direct Manufacturing of Elements for Next Generation Platform, funded by ESA under Artes 5.1
Contract No. 4000107892

Selection of measures

Selection of appropriate protection measures aims at matching the components requirements with restrictions of the protection measures as e.g. space on a surface required for a marking measure. Measures that have not been excluded by K.O. criteria need to be rated in terms of benefits and effort to implement them depending on the specific part and its function. The result of this phase is a prioritized list of measures that may be implemented in the following step. Even a combination of measures is possible and increases the protective effect.

Application of measure(s)

The main activities of the application methodology are concentrated in this final step that is strongly depending on the specific component and measure selected in the previous phases. Subsequent to the selection the appropriate protective measure for the product the envisaged implementation of the measure has to be carried out. Therefore decisions on factors of the manufacturing process, the component and the protection measure are essential. The aim of the individual decisions is to narrow down the number of ways to implement the measure and thus to obtain in the best case only one way as a recommendation for the implementation in the end.

First decisions on component-related factors are taken. This group covers any aspects which narrow the implementation and depend on the product. These include the manufacturing-related factors as a subsystem and the determination of the available space on the component. In turn the manufacturing-related factors include the selection of the manufacturing process and the determination of the orientation. In general the process is defined by the component and not by the protection measure. Protection measures can also occur as a structural component by which the measure itself becomes a component. In this case a decision on the manufacturing process is necessary. For example an internal barcode can be created in a plate which is then fixed again on the actual product. By defining the manufacturing process the possibilities of implementing a measure on a specific product are already limited. Following to the process selection the orientation of the measure in the component and thus in the building chamber has to be chosen. Due to the layer wise manufacturing of AM this selection causes further narrowing. An example of this is the de-standardized screw. By using AM round body shapes can be produced more precisely in the z-direction than in x or y. This means that a screw which is built horizontally in the building chamber has a major deviation and thus a bigger clearance has to be provided to the thread. With the selection of the manufacturing process and the determination of the orientation manufacturing-related factors are completed. In the field of component-related factors the determination of the available space is left over as the next decision. For this decision the example of a barcode can be used again. Due to the limited resolution of the individual AM methods a barcode can not be made arbitrarily small. Therefore a minimum available volume in the component is needed.

In addition to manufacturing-related and component-related factors also protection-measure-related factors exist. These include the selection of the target group. Here particularly the question of traceability of products is vital. If a product shall be assigned clearly by the customer by using a protection measure, it has to be readily identifiable and difficult to copy. If on the other hand the original manufacturer wants to integrate a mark to be prepared for possible claims of recourse, the mark should not be identifiable neither to the customer nor to the imitator. Additionally to the selection of the target group the protection-measure-related factors include the definition of transferability to other products. For protection measures such as the "corporate design" it is important that these can be transferred without any changes to other products, which limits the possibilities to implement a product protection measure.

Finally the last step before the integrating the protection measure to a product is to check the profitability of a measure. Here the expected loss caused by an imitation has to be contrasted to the costs of a protection measure. Only if the costs are lower than the expected loss the selected protection measure should be used. Thus subsequently to the selection of a protection measure a total of six decisions have to be taken, which reduce the possibilities for the implementation to a minimum. Depending on the protection measure and the product or component it is also possible that a decision will lead to no remaining realizable solution. In this case prefixed decisions either have to be reconsidered or another protection measure has to be chosen. However, if the desired case that a small number of possibilities or ideally even just one possibility remains, the six decisions guarantee a reasonable implementation of the measure with regard to the economical and production-oriented perspective.

Summary and Outlook

The threat of product piracy will increase further in the future in particular if innovative technologies are wide spread and the usability increases due to supporting software. AM might ease copying and imitating products in combination with scanning systems but on the other hand it can be used to increase the effort for these activities as well. But there is one important statement that can be pointed out after two years of research dealing with product piracy and AM. Most of the measures developed and described in the catalogue can be implemented in products without increasing the design effort too much when considered already in the early stages of the development process. Thus AM allows a protection or at least a marking of product for traceability and to avoid product liability for imitated products roughly for free as individualization does not increase production costs. To reduce effort and costs for designing these individual markings and allow the traceability over a product's lifecycle supporting software solutions are in development at the University of Paderborn. Finally the demonstrator produced in Selective Laser Sintering (see *figure 5*) shows a couple of measures combined in one product. Various product-related measures as functional integration and the implied and in this case unclosed black box help to imagine what becomes possible. In the left figure markings are visible that are integrated in the housing as an internal QR code, a RFID chip is not directly producible in this manufacturing process but can be integrated by designing two parts from fitting to each other. The ball with its internal structures on the right shows a peculiar design of a QR code so that it only becomes visible and scannable in the intended perspective.



figure 5: Product for demonstration of various protection measures

As a general recommendation the protection measures using AM should be considered directly during the development and design phase of products. Even though a holistic protection consists of measures covering all categories including legal and strategic aspects, a technical protection using AM will have a preventive effect and does not increase the costs significantly. The awareness regarding product piracy needs to be increased in public and the consideration of protection measures, not only of AM measures, should be integrated in development processes over long term.

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