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Design for protection: Systematic approach to prevent product piracy during product development using AM

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Abstract

Although infringements of intellectual properties in terms of product piracy are growing for years and threaten investments in research and development most companies still rely on legal measures like property rights. A more preventive effect to protect against counterfeits can be achieved using technical measures complicating reverse engineering, improving traceability and assuring data protection. Additive Manufacturing can contribute a lot to the effectivity and efficiency of those technical measures but presently they are often unconsidered during product development. To support decision makers and designers through all the steps of a product development process an integrated systematic approach has been developed. Protective measures using AM are allocated to specific process steps and responsible persons in charge so that the result is a guideline for "design for protection". The main idea is to help developing piracy-robust products for that the return of investment is not threatened by counterfeits and its economical impacts.

Introduction and motivation

Branches dealing with mechanical and electrical engineering and manufacturing of systems like the automotive or electronics industry currently benefit a lot from globalization, decreasing costs for logistics and advanced infrastructures of information and communication technologies (ICT). [AKL11] Based on innovation and unprecedented productivity due to automation of manufacturing systems the German machine and plant engineering industry came up with up to now highest turnover volume of 218.1 billion € in 2015. [VDMA16] Between 2012 and 2015 more than every second company in mechanical engineering developed new products and/or processes and gained more than 20% or their turnover with novelties on the market. To continue on this success companies spend billions of € in their capabilities for innovations. [ZEW16] Exactly those investments and generated competitive advantages are highly threatened by imitations. PORTER stated already in 1985 out that the sustainability of competitive advantages can only be kept by implementation of inherent barriers hampering rivals to imitate innovation independent from the legal point of view. [Por85] As globalization, decreasing costs in logistics and the proceeding ICT infrastructure pushes innovations on the one side it brings up new risks on the other side. [WAB+07] [BMF16] In relation to simple consumer goods the number of imitations of highly complex products up to whole machines is increasing further. [VDM16]

It seems like the words of Confucius are still very newsworthy:

"By three methods we may learn wisdom: First, by reflection, which is noblest; Second, by imitation, which is easiest;
and third by experience, which is the bitterest."

Unfortunately it is the second methods that is used more and more. Regarding the initiative "business action to stop counterfeiting and piracy (BASCAP)" the easiest method of learning wisdom ends up in economical damages of roughly 1.770 trillion US $ only in 2015. [BAS11] More detailed information are shown in biennial studies by the German Engineering Association (VDMA). According to their study "Produktpiraterie" 70% of the associated companies are affected by imitations with a total damage of 7.3 billion € in 2016. Additionally and very hard to quantify are damages that will occur in the future in terms of loss of images caused by imitation not satisfying or even endangering customers. Particularly the risks for customers' health, especially for children's health, are focused in the European H2020 project "iBUS – integrated business models for customer driven custom supply chains". Innovative solutions to customize toys and therefore come up with added values and increased satisfaction are in development in this project. To meet European regulations regarding toys' safety is one the most important topic when thinking about customer driven designs. Imitations, not only poor and low quality copies, are a considerable threat violating European regulations in many cases. Derived from the findings in the iBUS project and the alerting figures shown in the studies a preventive protection against product piracy and counterfeits should be integrated in innovation and development processes of companies across different branches. At least the awareness has to be raised to make a conscious decision. [VDM16]

Today most companies try to protect their innovations and knowledge with legal measures that are mostly reactive except of a deterrent effect. But as the study made by the VDMA shows the most important source for product pirates is the reverse engineering re-generating product data from the physical product. Legal measure will not be able to prevent reverse engineering as the illegal activity is very obvious in most cases. Furthermore law is different according to the territorial principle and it is very hard to consider all relevant countries. [Lor12] In contract to that technical measure have an effect that is much more protecting against reverse engineering and not restricted regionally but only 29% of questioned companies implement technical measure in their products. Most of them because of their felt assessment that there are no technical measures available and effective.

Additive Manufacturing with its freedom in design, flexibility in production and those often mentioned benefits is able to contribute with new technical measures preventing product piracy. The main limitation using additive manufacturing and its protective technical measures is that a product's design has to be manufacturable additively. The fewest products designed for conventional manufacturing like injection molding or milling can be produced economically and/or technically in additive manufacturing processes without changing the design. Therefore the main intention of this paper is the integration of additive manufacturing and related technical possibilities to prevent imitations in standard development processes to support companies and designers to design for protection. According to KOKOSCHKA a lack of knowledge and awareness in the companies is responsible for the now enormous need of action. [Kok13] Thus the systematic approach will take all departments into account so that the whole topic will be considered company-widely in the future. A holistic, sustainable and integrated knowledge management will be a solution to spread the potentials of additive manufacturing, its applications to protect products against product piracy and recommendations for actions. In a first step the systematic will be embedded in a paper catalogue to be used by all players involved in the development of innovations.

Application centered requirements analysis

Divided in two subsections, formal and application based requirements, this section deals with the analysis and definition of requirements to be fulfilled by the systematic approach. The main aim is to consider all demands and issues so that the methodology will be integrable or applicable in the companies' process map.

Formal requirements

The objective of this subsection is to ensure a systematic and structured development and definition of the systematic approach respectively methodology. Thus the main requirements here are based on PATZAK [Pat82] who stated out that methodological models should be meet on the following five requirements to be effective:

- Empirical correctness: Model and empirical study will arise similar results,
- Formal correctness in terms of reproducibility and traceability,
- Case related to achieve a solution or benefit for the focused problem,
- Usability for easy use of model as well as for interpretation of results and
- Low-effort-applicability so that effort and profit have a good relation

Furthermore rules of systems engineering are considerable as the systematic approach will support protective development of complex products up to technical systems. HABERFELLNER summarizes those rules in four main thoughts: [HDWFV12]

- Development from rough to detailed
- Thinking in and about variations
- Breakdown in phases
- Enabling of cyclic problemsolving

Application based requirements

Requirements shown in table 1 are resulting out a of more deep analysis of background in terms of where does the problem come from and how are companies acting in the development of new and innovative products. The table is divided in three sections of requirements on the systematic approach: Regrading product protection, regarding knowledge management and regarding additive manufacturing:

Product protection requirements are shown from R1 to R7. Knowledge management requirements to be fulfilled by the systematic approach are specified in R8 and R9 and finally as the whole approach aims at enabling companies to use additive manufacturing for a protection against counterfeits R10 brings that into account.

Table 1: Requirements for systematic approach in three sections: Regrading product protection, regarding knowledge management and regarding additive manufacturing

No.	Requirement	Description
R1	**Product protection has to start already on a strategic level**	*Measures has to be considered in early phases of product development and have to be intended by the whole company*
R2	**Methodological support during whole product development process**	*Support has to start during concept phase to prevent non economical redesign afterwards. Further it should not stop before production system development*
R3	**Identification of components/function worthy to be protected**	*In most cases not the whole product has to be protected but only most important functional components*
R4	**Consideration of surrounding conditions of companies**	*Methodology should be applicable across branches but precise for a specific company*
R5	**Methodological support of protection measures in product and production development**	*In particular the support of designers has to be driven by the systematic approach as they are responsible for implementation of technical measures*
R6	**Reduction of complexity**	*It should not increase efforts when using methodology*
R7	**Selection of combinations of protection measures**	*Mostly implementation of one measure is not sufficient as threats come from different sources. Therefore combinations should be considered*
R8	**Expatiation of knowledge about product protection**	*The systematic approach should allow to transfer implicit knowledge to be reused by others*
R9	**Concise presentation of results**	*Presentation of results is the basis for further decisions and trade offs*
R10	**Consideration of manufacturability in AM**	*To protect products using AM the selected components and measures has to be manufacturable additively*

Analysis of systematic approaches for product development

There are a couple of approaches to foster the protection of product and therefore to increase the resilience against product piracy. Without going too much into detail all of those approaches have been assessed regarding their degree of fulfillment the previously defined requirements. Detailed analysis of each approach has built the basis for the rating shown in table 2. All necessary information needed for transparency and reproducibility of the assessment are available in the primary sources given in the following section. The existing approaches have been clustered in three sections regarding their main aim:

- *Development of product-protection strategies*

  Previously to the research offensive driven by the Federal Ministry for Education and Research (BMBF) in Germany in 2010 there have been three approaches existing that are wide spread in the literature made by JACOBS et al., FUCHS and VON WELSER und GONZALES. [JSJ01][FKMR06][WG07] In addition to those there came up a new one driven by the offensive published by GASSMANN und BECKENBAUER in 2010. [GB10]

- *Imitation-protected design of products*

  Four further approaches focusing a more application based procedure have also been developed during projects funded by the BMBF since 2010. The main objective here is to directly design protected product so that the strategic point of view is mostly missing. In the following table these approaches are named MEIMANN and the mentioned projects with their acronyms KoPiKomp, ProAuthent and KoPira. [Mei10][BJSR10][GDS10][AAG10]

- *Development of imitation-protected product and processes*

  Last but not least the considered approaches in this category combined already the good parts of both categories before so that they became more holistic. In comparison to the approaches mentioned before these ones are considering the areas procurement, manufacturing, distribution and information management as well. The considered approaches are described in detail by NEEMANN, SCHNAPPAUF, ABELE, MEIWALD, KLEINE und KOKOSCHKA. [Nee07][Sch10][AKL11] [Mei11][Kle10][Kok13]

Finally table 2 and the assessed approached respecting the defined requirements are showing a very white spot in consideration of AM potentials and in applicability as a holistic approach during the whole development process. None of the analyzed methodologies supports from the very first idea on a strategic layer over product development up to the development of the production system. Exactly this consistency through the whole process chain is missing resulting in coordination effort afterwards. Considering requirements and potentials of the production system directly at the beginning will help to avoid expensive changes prior to the start of production. Therefore table 2 shows the need for action having the main objective in mind: Bringing additive manufacturing technologies more into application increasing the image regarding product piracy as it is often seen as a technology pushing imitations and counterfeits.

Table 2: Assessment of currently existing approaches for development of protection strategies, protected design of products and imitation-protected products and processes

Assessment of existing protection approaches		Anforderungen									
Rating scale: ○ = not fulfilled ◑ = partly fulfilled ● = completely fulfilled		Product protection has to start already on a strategic level	Methodological support during whole product development process	Identification of components/function worthy to be protected	Consideration of surrounding conditions of companies	Methodological support of protection measures in product and production dev.	Reduction of complexity	Selection of combinations of protection measures	Expatiation of knowledge about product protection	Concise presentation of results	Consideration of manufacturability in AM
		R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
Development of prod.-protection strategies	Development of anti-piracy-strategy acc. to JACOBS et al.	○	○	◑	○	○	○	◑	○	○	○
	Anti-counterfeiting-process acc. to FUCHS et al.	◑	○	●	○	○	◑	◑	○	○	○
	Development of protection strategies acc. to WELSER und GONZALES	◑	○	●	○	○	○	○	○	○	○
	Manag. of know-how-loss acc. to GASSMANN und BECKENBAUER	◑	○	◑	○	○	○	○	○	◑	○
Imitation-protected design of products	Developement of imitation-protected products acc. to MEIMANN	○	◑	○	◑	◑	◑	○	○	◑	○
	Piracy-protection for components in capital goods (KoPiKomp)	○	○	◑	○	●	◑	○	○	◑	○
	Proactive protection against product pirates (ProAuthent)	○	○	●	○	◑	●	○	○	◑	○
	Piracy-risk and measure analysis (KoPira)	●	○	●	○	◑	◑	○	◑	○	○
Development of imitation-protected product and processes	Methodology for protection against productimitations acc. to NEEMANN	◑	○	●	○	●	○	●	○	◑	○
	Preventive plagiarism protection acc. to SCHNAPAUFF	○	○	●	◑	◑	●	◑	○	●	○
	Darmstädter model for development of defence strategy (ProOriginal)	●	○	◑	○	◑	●	○	◑	●	○
	Protection of product piracy and know-how-loss acc. to MEIWALD	◑	○	●	○	◑	◑	●	◑	●	○
	Protection concept for capital goods (PROTACTIVE)	◑	◑	◑	◑	●	○	●	○	◑	○
	Piracy-robust design of products and processes (PiratPro)	◑	◑	●	○	◑	●	◑	○	◑	○
	Coneption of imit.-protected products & production-sys. acc. to KOKOSCHKA	●	○	●	◑	●	●	●	◑	●	○

Modelling of design for protection systematic approach

As a first step the main idea to model a systematic for a design for protection approach is to go along with standard design methodologies that are wide spread and really used in the industry. Therefore from a German perspective the VDI2221 is used as a basis and will be modified in some phases to fulfill the requirements regarding the integration and consideration of additive manufacturing as well as knowledge management. Phases, task and methods to be applied as well as the phases' results are described in figure 1 that is divided in two sections again: The first phase in light grey has only to be carried out once for a company in a longer time period while the other phases in dark grey have to be carried out for each product to be protected.

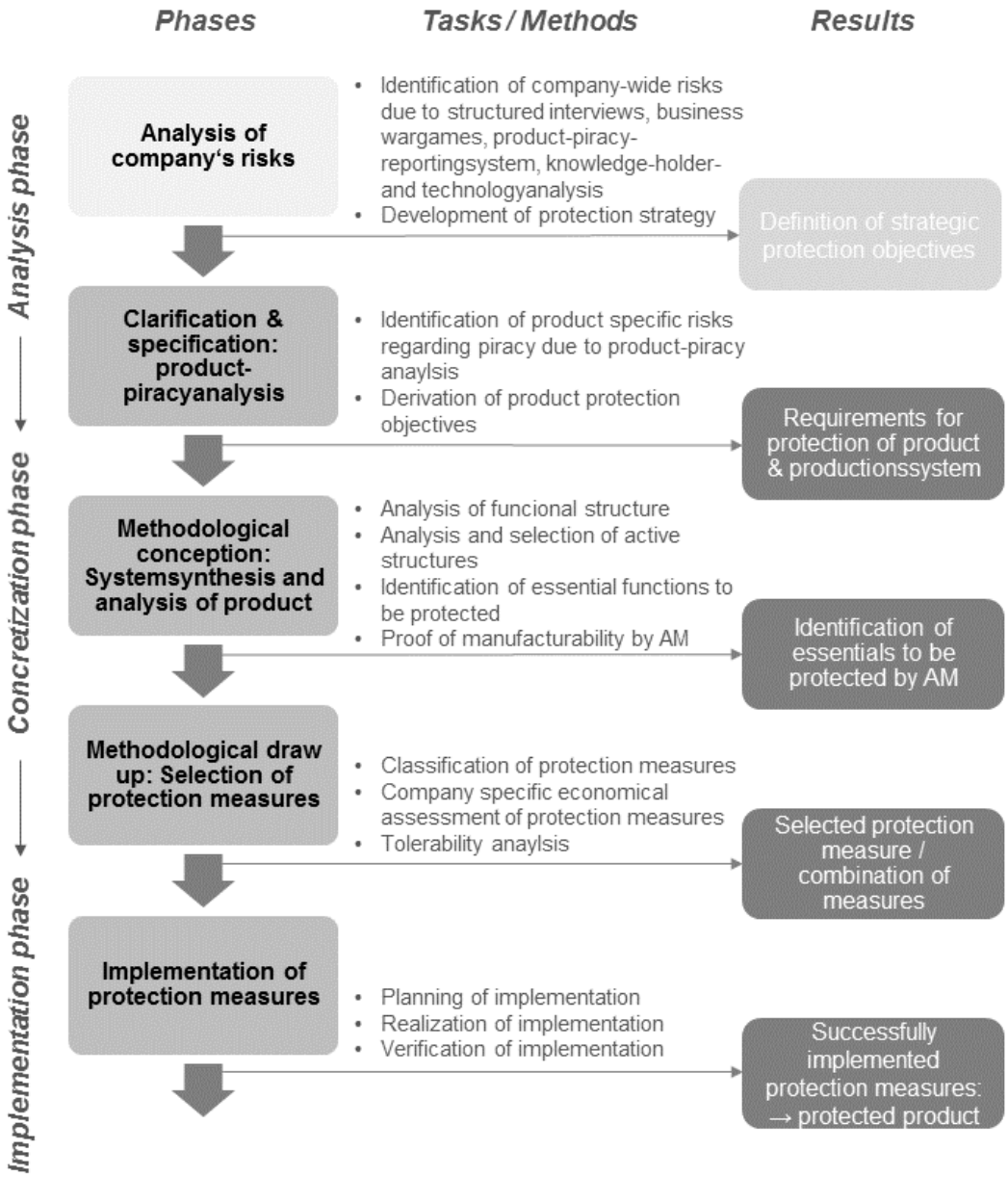


Figure 1: Assessment of currently existing approaches for development of protection strategies, protected design of products and imitation-protected products and processes

Integration of systematic in standard product development process

The integration the design systematic shown before in standard product development processes will enforce designers as well as product managers from a more strategic point of view to think about measures to prevent product piracy endangering for example in the toy industry children's safety and health. Also in other industries and branches product piracy might always come along with less safety due to inferior materials or manufacturing processes as the main aim here is to generate profit.

A model divided in three cycles focusing on the strategic product planning, the product development itself as well as the productionsystem development is one of the most holistic methodologies used in industrial and scientific areas. [GPW09] The main aim is to give an overview about the steps and responsible persons that are affected by the systematic approach. This will support an easy integration in companies' everyday life. One advantages of the three-cyclic-model acc. to GAUSEMEIER et al. is the interdisciplinary applicability so that it can be used for each product independent from the branch or industry up to smart products with a high degree of automation and intelligence. [GEW09] Figure 2 shows the adapted model and assigned activities.

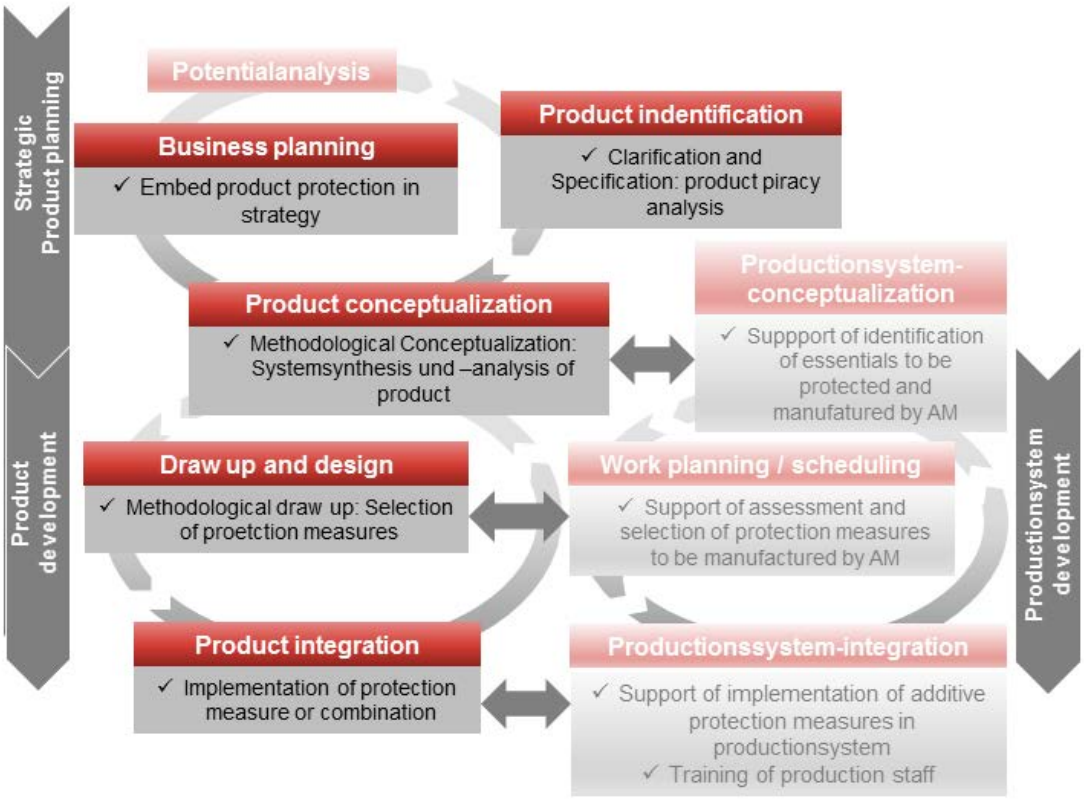
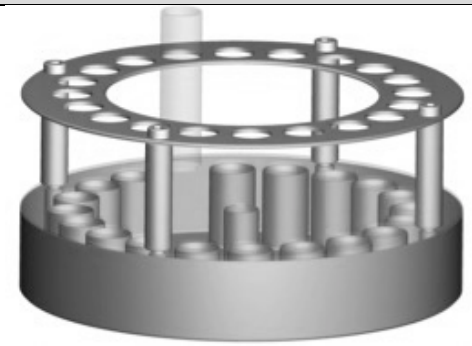
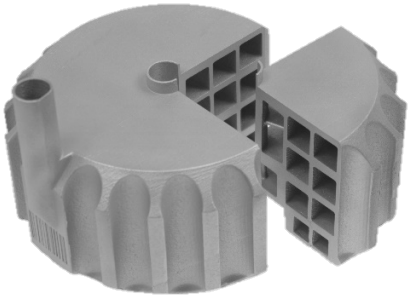


Figure 2: Integration of systematic approach for a design for protection using AM in the three-cyclic-model from business planning to start of production acc. to GAUSEMEIER [GEW09]

Validation of systematic approach protecting an industrial application

To validate the designed systematic approach to protect products against product piracy and counterfeits and further misuse an industrial application and its transformation from a very first idea to a protected additively manufactures product is presented in table 3. All the step defined in figure 1 have been carried out with resulting in a very resilient product.

Table 3: Assessment of currently existing approaches for development of protection strategies, protected design of products and imitation-protected products and processes

Application example: Sample collector system for bioreactors	
 Figure 3a: First idea for convential manufacturing	 Figure 3b: Part „designed for protection“ with AM
Brief description	
The shown sample holder carousel is designed for the use in a sample collecting system to be used for automatic sampling of nutrient solution of bioreactors. The first idea (on the left side) shows a design for conventional manufacturing fulfilling most of the intended functions but without any protection against counterfeiting. Proofing potential risks in the 5 step approach the resilience against reverse engineering has been assessed to be very poor. Following to that this part has been selected during the identification phase. It is very important for the intended functionality of the whole system as well as manufacturable additively. Thinking about potential protective measures already published at the SFF a couple of measures has been selected with very good synergies. [JBR15] The measures and resulting benefits are described in the following cell. Finally the last phase aimed at realization of the analyzed functional structure considering the selected measures during the design. In terms of knowledge management this table can act as a kind of fact sheet to be used by designers to benefit from already achieved success stories.	
Manufacturing process:	Selectives Lasermelting (SLM)
Material:	AlSi10Mg
Batch size:	depending on demand - envisaged: 100+/year
Applied AM potentials and resulting benefits	
Tool-less manufacturing: Due to the manufacturing using SLM in this application example conventional manufacturing has only been used for removing of support materials.	
Flexible Production: During development there have been six iterations for draft designs until the final one has been proofed to be robust manufacturable and protected against reverse engineering. As there are no tools needed the effort was very low to go through these	

itereations. Only changes in 3D CAD has been necessary. After development phase this potential is very useful for the economical production driven by demand.

Freedom of design: Using the possibilities in design that are offered by AM a functional integration has been realized resulting in a design for protection.

Individualization: Each part is marked with an individual code for traceability so that counterfeits can be distinguished from the original one as there are visible and invisible markings as well. Therefore an identification becomes possible on the one hand and authentication on the other.

Safety against product piracy: All the mentioned potentials applied in this design for protection end up in safety against product piracy as for example reverse engineering is complicating by far and traceability is pushed.

Conclusion and outlook

Summarizing the systematic approach and its validation safety against product piracy can be achieved using this structured methodology. Due to the fact that the VDI2221 design methodology is very wide spread and in industrial application the defined approach is very usable as there are a just modifications made to integrate missing topics like AM conformity and knowledge management. In this paper knowledge management is coming off badly as the whole approach need to be used over a longer term so that a kind of design catalogue can arise showing more example like the sample collector. In that way designer will be supported learning from already made success stories. This is exactly what needs to happen in the future. The process steps and phases are spread in the industry and there will come back feedback and applications to be collected in supporting guidelines to foster more and more designs for protection.

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