2 The DGLs-CF — Introduction and Background

The DGLs-CF is a methodological approach for product design and process reconfiguration, aimed at effectively helping and leading the activities of designers, manufacturers and inspectors. The initial consideration is that designers are not necessarily experts in manufacturing and verification processes; likewise, manufacturers and inspectors might not be experts in design. As said in the previous chapter, the birth and evolution of the DGLs-CF took place in a scenario where tools and methods for product development have been analysed from a concurrent engineering point of view, and where the adoption of standards is a key point.

Considering the terminology explained in the previous chapter, the DGLs-CF may be considered essentially a design for multi-X method. At the beginning, the former DGLs were developed as a simple DfM method, particularly focused on establishing guidelines for product design considering the characteristics of some manufacturing processes. Subsequent improvements highlighted other interesting peculiarities that started to differentiate the DGLs from the classic DfX methods. According to the ISO GPS vision, it was also considered that the verification process affects the design phase, so that verification aspects have been evaluated together with the manufacturing ones. A sort of Design for Manufacturing and Verification method was the result, to link design, manufacturing and verification in a new way. The study and development of the DGLs-CF as a design for multi-X method, strictly connected with the ISO GPS standards, can be considered the most interesting issue of the whole research.

Figure 2.1 shows the role of the DGLs-CF in the product development process. The full-line boxes and arrows represent the knowledge and its flow corresponding to the structure of the former DGLs, while the dashed elements correspond to the new aspects introduced by the DGLs-CF.

The contribution of the DGLs-CF, actually representing a differentiation from the classic DfX methods, stands in the fact that knowledge evaluation not only generates guidelines for product development, but also for process reconfiguration. Not only guidelines to redesign the product according with the manufacturing and verification characteristics are given, but also guidelines to reconfigure the manufacturing/verification processes specifically for the redesigned product. Anyway, the attention is always focused on the product; the process reconfiguration must be intended as a process customisation where the different representations of the product — digital model or physical part — are managed and modified. For now, there is no redefinition of the general parameters of the process. As said before, all of this is shown in Fig. 2.1, where this additional knowledge generation and flow is depicted by the dashed box and arrows.

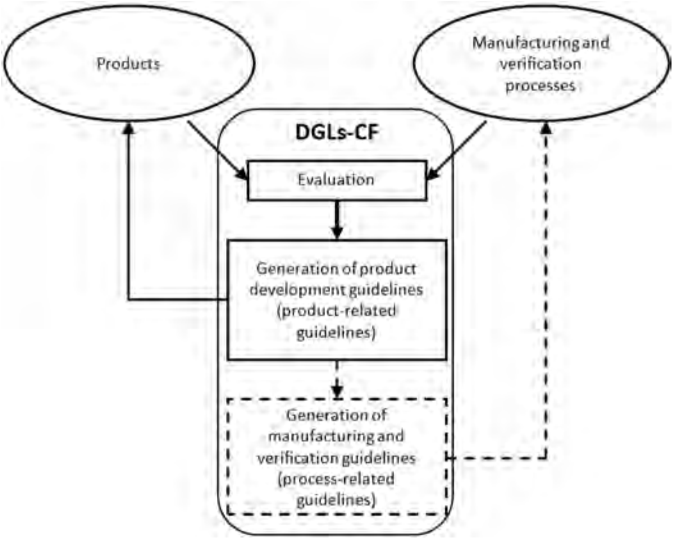

Fig. 2.1 Role of the DGLs-CF as a design for multi-X method in the product lifecycle

From this new point of view, the specific product is generated by exploiting the specific process characteristics effectively and adequately, since the product is tailored to manufacturing and verification processes, and vice versa.

2.1 Overview of the History of the DGLs

Detailed descriptions of the several releases of the DGLs were given by Bandera et al. (2004, 2005, 2006), Cristofolini et al. (2006), Filippi et al. (2001) and Filippi and Cristofolini (2007). Several fundamental aspects are recalled here to make the understanding of what follows easier.

The DGLs development started from two main considerations.

The redesign activities must remain the responsibility of the designers. Quite often today, manufacturers carry out redesign activities in order to improve the feasibility of products with particular technologies, but this is potentially dangerous; the operators may have little knowledge of the product domain and may not take the best decision in the case of multiple choices. Even worse, sometimes they may prejudice the model functions (Kumaran and Chittaro 1998). Moreover, designers need specific knowledge of the manufacturing processes to succeed in redesign (Haffey and Duffy 2000).

Design rules and handbooks existing in the literature now represent the only help for designers in modifying the product. Even if constituting a good starting point, they show some limitations that severely reduce their usability (Nielsen 1993) and the consequent effectiveness during the design phase. In fact, they do not have a structure that is helpful in generating, managing and using the rules; there is a lack of application criteria to guide the redesign activities; overall, they impose a scarce autonomy due to the fact that they have not been specifically produced for designers.

Three releases of the DGLs exist, corresponding to three important milestones during their development. They are briefly introduced hereafter, and the following paragraphs describe them in detail. The DGLs-CF, representing both the target of the research about a new concept of DfX method and the starting point for further theoretical and applicative research, will be described and applied in the field in the next two chapters of this book.

In their first release, the DGLs were based on a set of design rules that completed the existing set in literature and increased the possibilities of their use as an effective guide for the modification of a product during the design phase. Modifications guaranteed not only that the model could be built with particular technology, but also that the building process was advantageous when compared to other technologies, thus exploiting its capabilities and minimising time and costs. This concept is the basis for the definition of the so-called positive rules that will be recalled more than once throughout the book.

In the second release of the DGLs, the attention was on the verification phase, following the idea that the product quality could be improved when considering at the design phase not only the manufacturing process, but also the verification one. In this way, the DGLs enlarged their field of application in realising links between design and verification, according to the ISO GPS concepts.

Finally, in the third release of the DGLs the impact in terms of process reconfiguration was evaluated in depth; in this way the knowledge sharing among designers, manufacturers and verification experts became biunique. In a true concurrent engineering environment, the DGLs suggested the way to redesign the product and to reconfigure the processes to obtain and maintain the required functionalities.

This chapter goes ahead with the description of these three releases of the DGLs. They have been considered in this book because the development of each of them generated new and heterogeneous knowledge about the problem — the product redesign and process reconfiguration — and about the method to solve it — the DGLs-CF. The DGLs-CF answers almost all the questions and hints coming from these previous releases. Moreover, the evolution of the whole development process could be considered for similar situations in different application domains.

Each description shows quite the same structure, an introductory paragraph followed by three elements: the conceptual diagram representing the process for gathering and deriving the knowledge, the knowledge matrix that describes the data structure used to encode this knowledge, and the pros and cons at the end of each description that weigh the importance of the results reached and list the directions for the next release. The description of the third release of the DGLs diverges slightly from this structure; the complexity of this release required a sort of roadmap for its application in the field and this new element has been used as a tool to explain the release. Moreover, the descriptions of the three releases contain some case studies to clarify the effects of the DGLs adoption in some real industrial domains.

2.2 First Release of the DGLs. The Beginning

The first release of the DGLs was derived directly from the authors' experience in the field as mechanical designers and Rapid Prototyping — RP — experts. The characteristics of RP technology named Direct Metal Laser Sintering — DMLS — were analysed first, in terms of advantages and drawbacks; then, how these characteristics could affect the product redesign has been investigated (Filippi et al. 2001).

The DMLS process was chosen because this is one of the most promising RP technologies currently available. It can build metal objects using the same material as that of the final product. This characteristic widens the field of application of this technology, which can also be used in rapid tooling, i.e. for the generation of inserts for plastic injection moulding (Kuzman et al. 2001; Nelson 2002), and in rapid manufacturing, to build small series of complex mechanical parts (Gatto and Iuliano 1998; Jacobs 1995). On the other hand, the DMLS process shows some critical aspects mainly due to the behaviour of metal powders, such as complex sintering dynamics, residual stress, thermal deformation, etc. (Agarwala et al. 1995), so that more study is needed to solve or avoid current limitations even in early activities, for example during the design phase (Otto and Wood 2000).

At the beginning of the development of this release, the attention was mainly focused on collecting knowledge in a spreadsheet as in the work of La Trobe-Bateman and Wild (2003), and in generating rules to link the design and the manufacturing domains; after that, some software development and concerns about usability issues took place.

2.2.1 Conceptual Diagram

The conceptual diagram in Fig. 2.2 shows that this release of the DGLs has been heavily influenced by the considerations about the manufacturing technologies.

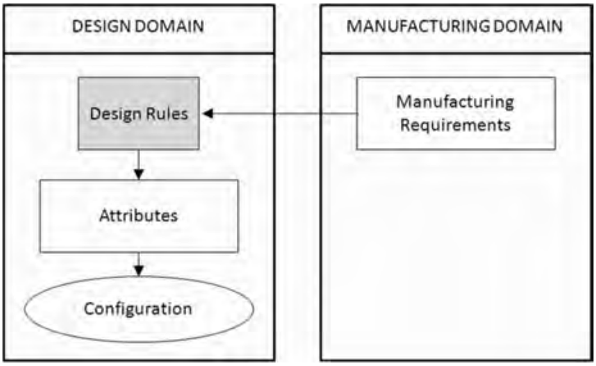

Fig. 2.2 Conceptual diagram of knowledge generation in the first release of the DGLs

Two domains were present, design and manufacturing, and, starting from the manufacturing requirements, a set of design rules was derived. Then the product was characterised in terms of attributes. The match between design rules and attributes gave a configuration, expressed in terms of activities to be performed on the product to make it compatible with the manufacturing technology.

2.2.2 Knowledge Matrix

Table 2.1 shows the knowledge matrix of this release of the DGLs. This matrix represents the knowledge structure and contains some examples of pieces of information, expressed in terms of manufacturing requirements, design rules, attributes and redesign solutions. Each row represents a different requirement with an associated design rule. For each rule there is one attribute that allows the characterisation of the product. For each requirement, redesign solutions are suggested to be used when the product does not match the rule.

After the definition of the data structure and the collection of some pieces of information, a very simple software prototype was generated using Microsoft Access. This implementation is of interest here because it allowed applying some refinements to the knowledge content of the DGLs. For example, the consequences of the violation of each rule and a coarse evaluation of the required post-process manufacturing cost — using a qualitative low-medium-high ranking — were defined; moreover, each hint — redesign solution — had its redesign cost associated. Finally, a picture explained the meaning of the rule. Figure 2.3 shows the form containing the description of a rule, with some comments about the meaning of the fields used.

Table 2.1 Knowledge matrix of the first release of the DGLs

Manufacturing requirements	Design rules	Attributes	Descriptions	Redesign solutions
Assure compatibility between workpiece dimensions and workspace of the sintering machine (workspace is 250×250×185 mm)	Keep maximum size below 185 mm	Maximum size	Maximum size of the model	Split the model
Minimise building time (building time increases with the height)	Minimise the height	Height	Height of the model	Split the model Change orientation
Assure proper building conditions (the recoater may cause bending of parts with high form ratios)	Minimise the form ratio	Form ratio	Ratio between the height and the horizontal cross-section of the model	Change orientation Add reinforcing structures
Minimise post-processing operations (lower surfaces require external support which has to be removed subsequently)	Avoid lower surfaces	Lower surfaces	Surfaces oriented downward with an angle <30° from the horizontal	Add overhangs Change orientation
Minimise post-processing operations (average roughness of DMLS parts is 15μm)	Avoid surfaces with a required roughness < 15 μm	Surface texture	Roughness value	None

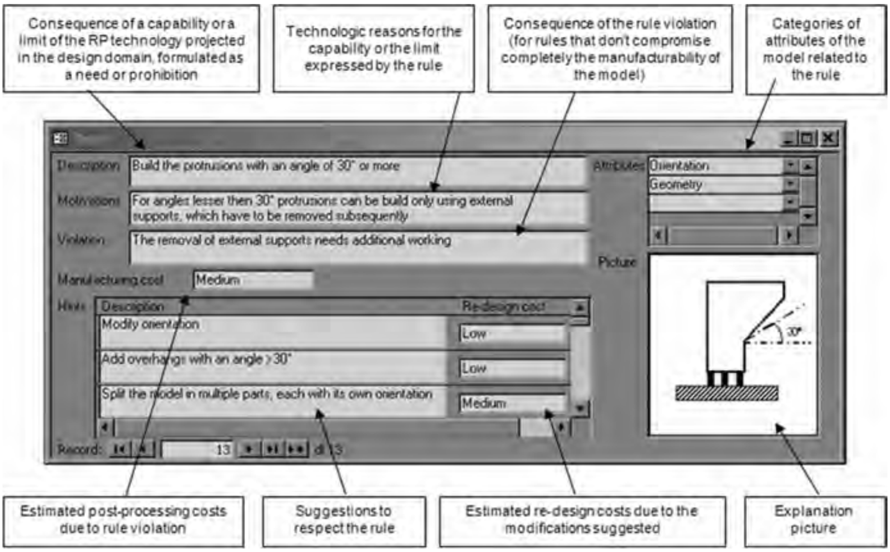

Fig. 2.3 Description of a rule using a form of the Microsoft Access database developed for the first release of the DGLs

2.2.3 Case Study

A coffee machine to be manufactured with the DMLS process was used as a case study to illustrate the adoption of this release of the DGLs in the field. This adoption consisted of a three-step procedure: product description, compatibility check, and configuration of the redesign choices. The description of this case study is based on Fig. 2.4, showing the model of the product under evaluation, and on Fig. 2.5, where the forms of the software prototypes corresponding to the three steps of the procedure are depicted.

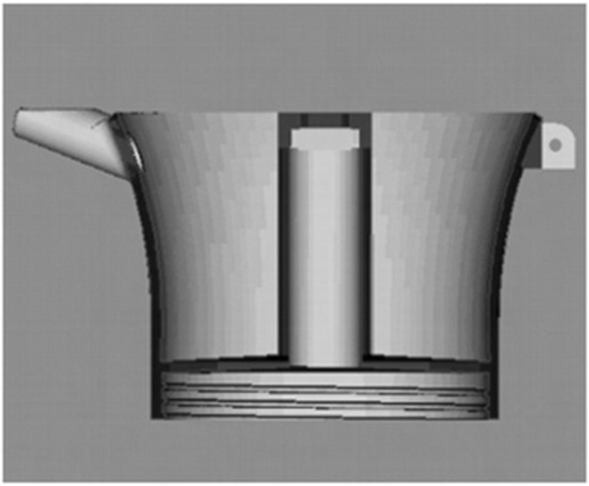

Fig. 2.4 Starting product model - section - of the body of the coffee machine used in the case study

Step 1. Product Description Figure 2.4 shows the section of the starting model of the coffee machine, while Fig. 2.5a reports an example of the attributes used to describe it. These attributes represented the functional components of the product, and they could be related to the following classes: geometry, dimensions, orientation, finishing, precision, mechanical behaviour and physical properties. Given this description, a set of rules for the current product was selected automatically from the database of rules related to the DMLS technology.

Step 2. Compatibility Check For each attribute of the coffee machine, the database showed the list of the rules that could be related to it, as shown in Fig. 2.5b. Then the user checked manually whether these rules were really pertinent to the current situation and, if yes, if they appeared violated or not.

Step 3. Configuration of the Redesign Choices For each critical situation highlighted before, the user made some choices that led the redesign activities. In this very important step, the software prototype generated a report containing all the information required for the next tasks. The left side of the form in Fig. 2.5c lists all the attributes; for each of them, the right side contains the knowledge related to the incompatibilities, expressed by the hints to solve the problems and the related costs.

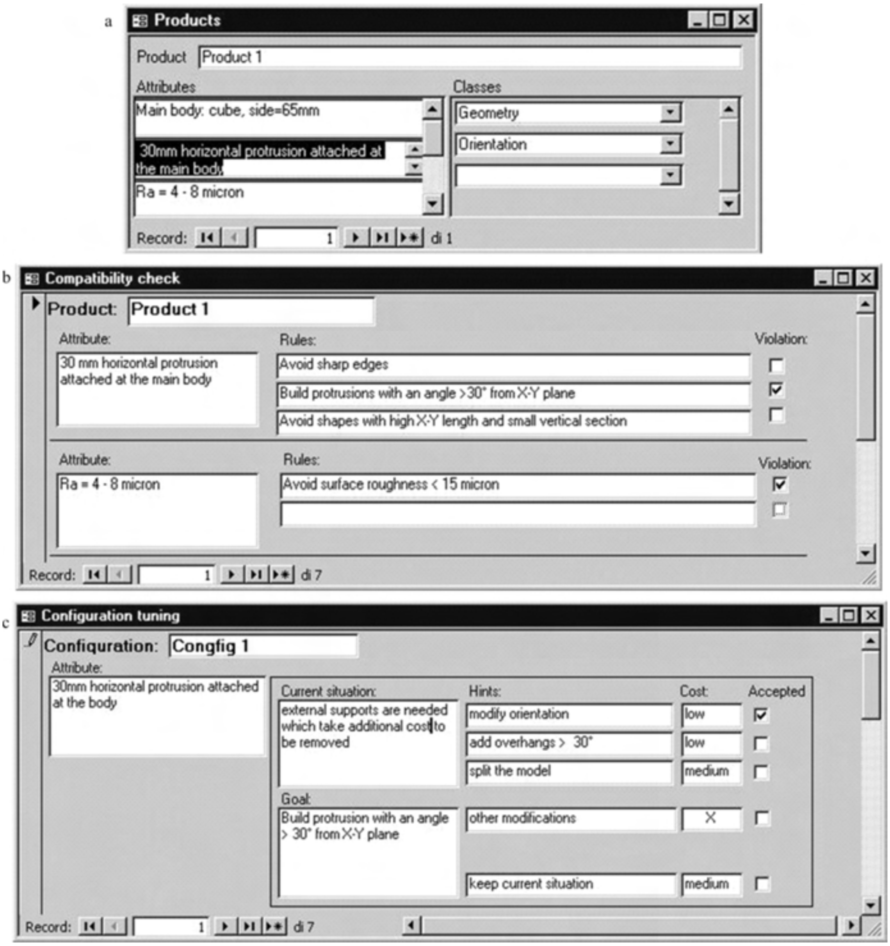

Fig. 2.5 Forms representing the three-step procedure of the DGLs adoption

In other words, the users of this software prototype defined a new product configuration, expressed as a collection of redesign activities. This happened because they were making some choices for each critical situation. The software prototype gave the total cost for the final configuration. The user could obviously generate more than one configuration, and compare them in the end. In the case of the coffee machine, two different configurations were considered, presenting different characteristics; in the first one, for example, the surfaces with a slope less than 30° were maintained unchanged, so some external supports would have been required; in the second, the product was changed in order to avoid supports. The comparison of the costs of these two configurations led to the choice of the second one. The chosen configuration contained also other suggestions for the reconfiguration of the model of the coffee machine. Figure 2.6 shows the result of the application of this configuration, while in Fig. 2.7 there is the physical prototype after the manufacturing activities.

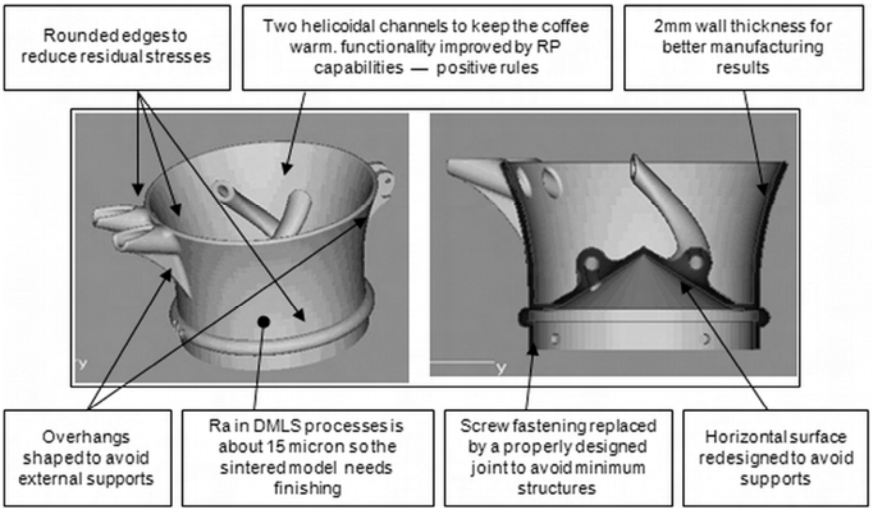

Fig. 2.6 Result of the redesign activities based on the DGLs adoption

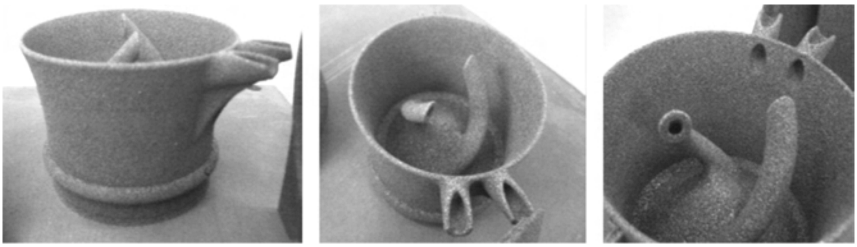

Fig. 2.7 The physical body of the coffee machine built using DMLS

The quality of the prototype confirmed the goodness and effectiveness of the guidelines. The coffee machine was successfully manufactured; it had quite good mechanical properties, given that it showed very few flaws. Moreover, void channels shaped like a helix were generated without problems and they represent a good example of the positive rules used to highlight and exploit the possibilities offered by the specific technology. The number of external supports was reduced as expected, to optimise the manufacturing process and minimise the post-processing activities. Nevertheless, the prototype presented some deficiencies: small parts were poorly manufactured in terms of precision and quality; some supports were generated corresponding to thin walls and for this reason the model could be damaged during the removal of them; moreover, somewhere it was not so clear where the supports finished and the prototype started. Finally, some supports were attached to non-flat surfaces, making support removal a difficult task. All of this means that the DGLs showed some deficits regarding the knowledge content, but this could also partly depend on the incomplete information coming from the manuals and literature about DMLS technology.

2.2.4 Discussion

Even if this first release of the DGLs allowed one to focus the main issues of the redesign process and generated some interesting results as in the case of the coffee machine, some problems, mistakes and open issues arose during the research. They are listed in the following, using a classification that will be exploited throughout the whole book.

Conceptual Diagram and Knowledge Organization

- The conceptual diagram was too simple and did not represent knowledge generation correctly as occurs in real application domains.
- The redesign column of the knowledge matrix did not have real corresponding elements in the conceptual diagram.
- The location of the domains and their characterization were wrong.
- The knowledge matrix structure could lead to considerable redundancy, for example when the same technological requirement required more rules, each one with several attributes.
- The distinction among the different domains present in the conceptual diagram was lost in the knowledge matrix. As will be clear in the following, this is a serious drawback.

Knowledge Description

- The descriptions of technological requirements, rules, attributes, etc. were always too general, with no quantification.
- Product characterisation is one of the most important issues of the whole research. It is an intrinsically difficult task, given the large number of degrees of freedom involved. In this first release of the DGLs, this characterisation was extremely simple, merely to test the complete process, from product characterisation to product redesign.

Costs

- Costs were managed in an extremely coarse way. They were considered just to set a future role for them and to check some minimal related functionality.

Implementation/Automatisms

- There was nothing automatic or, at least, semi-automatic. This release of the DGLs was a simple database with an interface. There was no data processing at all and users must do everything themselves.

2.3 Second Release of the DGLs. Improvements and the Synergy with the ISO GPS

The remarks in the previous paragraphs were considered as the starting point for the next release of the DGLs. The attempt to eliminate problems and mistakes was coupled with an effort to widen the view, considering other aspects of the product lifecycle. A synergy started with some experts in product verification, focusing on the dimensional, micro- and macro-geometrical issues (Bandera et al. 2004, 2005). All of this led to the adoption of the ISO GPS principles. In this context, the analysis of the possible interaction/integration between the DGLs and the ISO GPS seemed very interesting and convenient for many reasons. The closeness between the DGLs and the ISO GPS was immediately clear, from a conceptual point of view, because both of them are basically tools to help the designer in specifying, refining and communicating the product characteristics. As the DGLs were a design tool related to a specific manufacturing process, the possibility and opportunity of revising their structure and contents to agree with ISO GPS concepts seemed of great interest. This could signify establishing the possibility of making a real link between design, manufacturing and verification, and enlarging in this way the DGLs application domain.

As explained below, ISO GPS principles have been actively adopted for updating the generation and the formalisation of knowledge within the DGLs. The most important new elements in this release of the DGLs were the introduction of a new domain — the verification domain, a classification of requirements and rules, and a new knowledge matrix layout.

2.3.1 Conceptual Diagram

Figure 2.8 shows the conceptual diagram of this release of the DGLs. There were three domains, and the manufacturing and verification ones determined two different sets of requirements. Two sets of rules arose directly from them: the DfM rules, and the DfV rules. The attributes used for describing the product came from both these sets. The product configuration, once defined in terms of attribute values, determined the generation of the last two sets of derived rules: manufacturing rules and verification rules. The meaning of all these elements should be clear considering the content of the knowledge matrix. It can be seen that here the new aspects of the DGLs start to become evident; manufacturing rules and verification rules and their flow of information, represented with dashed arrows and boxes, correspond quite well to the dashed elements shown in Fig. 2.1.

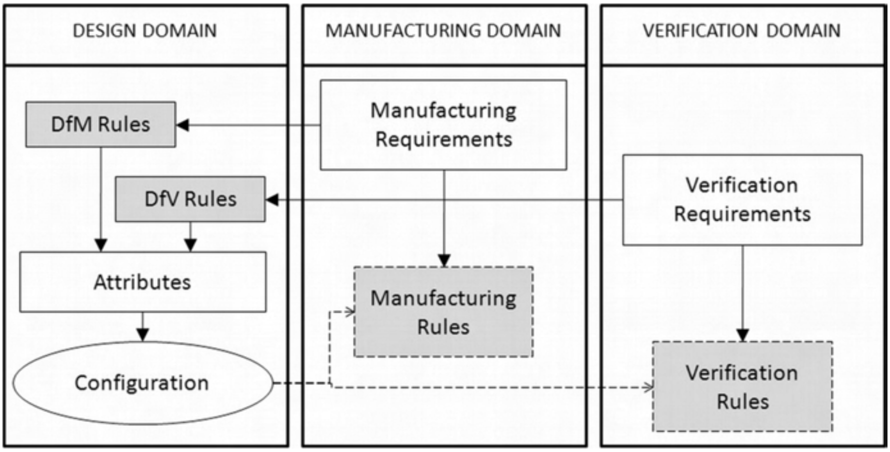

Fig. 2.8 Conceptual diagram of the second release of the DGLs

2.3.2 Knowledge Matrix

As regards the knowledge matrix, there are many new elements and issues to consider here. First of all, the layout of the matrix shown in Table 2.2 did not match the conceptual diagram. This is because the idea was to bring the knowledge structure closer to the final user than to the system implementation. The attributes, the most important elements from the users' point of view, appeared in the left side of the matrix. Then there were the DfM and DfV rules with the different attributes. To the right there were the manufacturing and verification requirements that, in a sense, justify the presence of the rules and of the attributes. For each attribute, in the lower part of the knowledge matrix there were the manufacturing rules and the verification rules selected during the definition of the product configuration and represented explicitly. These rules were kept separated from the others because they were related directly to the manufacturing and verification domains; they were not redesign rules.

Table 2.2 Knowledge matrix of the second release of the DGLs

Attribute	Description	DfM and DfV rules	Manufacturing requirements	Verification requirements
Height	Height of the model (linear dimension)	Minimise the height of the model	Minimise building time (building time depends on the height)	-
		On the basis of functional requirements and related dimensional tolerances, establish the verification method and indicate it on the drawing with proper symbols (for example, LP-two-point size; SN-Minimum statistical size; SX-Maximum statistical size; SA-Average statistical size) [a]	-	The verification methods and tools have to be chosen considering the characteristics of the features to measure
			Manufacturing rules	**Verification rules**
			Use thicker layers	Measure the height according to the indication established on the drawing

Attribute	Description	DfM and DfV rules	Manufacturing requirements	Verification requirements
Surface texture	Roughness value	Avoid surfaces with a required roughness < 15 μm	Minimise post-processing operations (average roughness of DMLS parts is 15 μm)	-
		Avoid locating surfaces with strict roughness specifications in deep and narrow cavities.	-	Assure enough space for standard measure instruments
			Manufacturing rules	**Verification rules**
			If fine surfaces are required, use 20 μm metal powder and thin layers	If the roughness verification is difficult to accomplish with standard instruments, evaluate the possibility of using non-contact surface measurement

[a] LP may be recommended for dimensions which are not critical, while for critical dimensions in assembly, statistical measurements could be preferred. Particularly, SN for external features, which have to guarantee a fitting with interference, SX for external features, which have to guarantee a fitting with clearance and SA for individual features.

2.3.3 Case Study

Also for this release of the DGLs a simple software package was developed and adopted in the field for the redesign of a mould insert for the production of a plastic part used in the textile industry. The problem to solve was a high cycle time and a poor quality of the moulded part due to an incorrect cooling of the mould. Figure 2.9 shows the plastic part with highlights corresponding to uncooled regions.

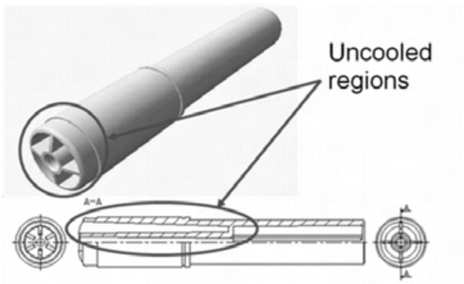

Fig. 2.9 The plastic part used in the case study of the second release of the DGLs

To solve the problem, the idea was to redesign the mould insert used to generate the cavities of the plastic part. Its feasibility with the DMLS technology was evaluated and improved with this second release of the DGLs. Design solutions were considered to avoid mechanical problems of the insert under moulding loads and to exploit at best the potentialities of the DMLS technology, by using again the positive rules. Figure 2.10 shows the evolution of the model of the insert due to the DGLs adoption. The main differences between the starting and the final configuration stand in a different number of dangling elements — three instead of four — in a different shape of cooling channels, and in the addition of some post-processed elements to improve the strength of the insert during the moulding. Moreover, given that it was important to ensure a good surface finish, as well as the coaxiality relationship between the inner hole and the external tapered surfaces, the attention to the verification issues was important as well.

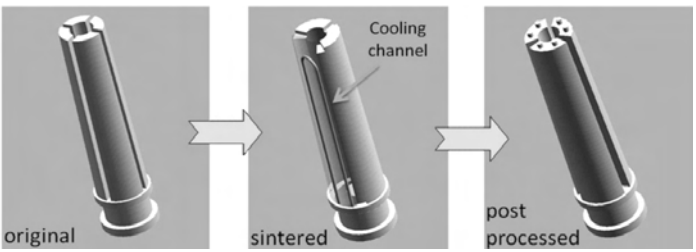

Fig. 2.10 Redesign of the mould insert thanks to the DGLs adoption

Figure 2.11 shows the mould where the redesigned insert was placed and the final plastic part generated using it.

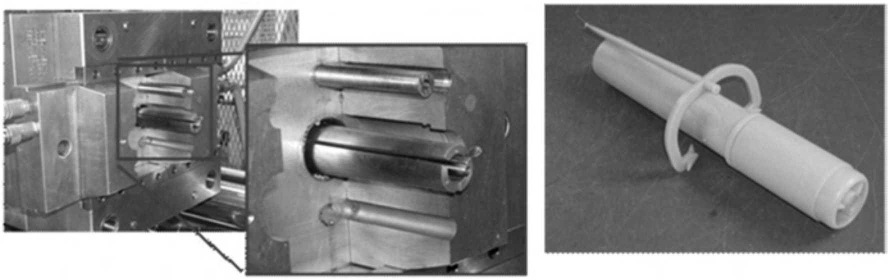

Fig. 2.11 Mould with the redesigned insert (*left*) and final moulded part (*right*)

2.3.4 Discussion

This paragraph, unlike the corresponding one in the description of the first release of the DGLs, opens with some final considerations about the positive outcomes of this release of the DGLs and about the problems solved. After that, the list of the remaining problems, mistakes, and open issues, is given as before.

Positive Outcomes

The ISO GPS adoption helped the development of this DGLs release in several aspects. Here product formalisation was much better and the consideration of the verification phase of the product lifecycle enhanced the coverage of this knowledge based tool, using a conceptual diagram closer to the real scenarios. The correspondence between the conceptual diagram for knowledge gathering and the knowledge matrix appeared enhanced as well. Moreover, regarding the quantitative aspects, some attributes with corresponding values were introduced.

Relating to the categories used to classify problems and open issues of the previous release, here something positive was done in the Conceptual diagram and knowledge organisation, and in Knowledge description. However, the experience described above gave some impressions on the presence of criticisms even on this revised version of the DGLs. They appear in the following.

Conceptual Diagram and Knowledge Organisation

- The knowledge gathering process was still wrong. The different pieces of information were misplaced; the derivation rules were rough. Sometimes there were coarse mistakes in the interpretation of the meaning of the data. For example, what were called here manufacturing or verification rules would have been better intended as a collection of hints to consider or actions that must be

performed. This is one of the main elements taken into consideration during the development of the next release of the DGLs.
- The structure of the knowledge matrix was unclear and ambiguous. Things were simpler in the first release, where the knowledge matrix was a plain table. Here the knowledge matrix was again a sort of table but the manufacturing and verification rules broke the table concept, introducing some asymmetry in the structure. At the same time, it was not a bi-dimensional matrix, as it was impossible to identify the two independent dimensions to label the rows and the columns.
- Redesign hints disappeared in attempting to make the knowledge matrix consistent with the conceptual diagram. Apparently this solved the problem of the previous release but this is untrue because the redesign hints were still present and, even worse, in a misunderstood way, in the form of manufacturing and verification rules.
- It should have been the time to adopt a clear formalism to label the items and the entities involved in the process.

Knowledge Description

- There was still a lack of quantification. Some attributes allowed consideration of numerical values — dimensions of the product, surface finishing values, etc. — but the approach was not systematic and these values were used to get an over-simple evaluation of the product compatibility with the manufacturing and verification activities.
- The possibilities offered by the ISO GPS to define a clear way to characterise the product to redesign have not been exploited enough.

Costs

- Costs completely disappeared in this release of the DGLs, mainly because the focus was on the ISO GPS adoption; it was quite clear that a serious and rigorous cost evaluation was impracticable at that moment.

Implementation/Automatisms

- Again, there were no automatisms in this second release of the DGLs, but, even worse, there wasn't any feeling about some serious identification of procedures and about the implementation of the corresponding software modules.

ISO GPS Adoption

- Even if the adoption of the ISO GPS introduced a high added-value to the DGLs, too few ISO GPS concepts have been exploited. For example, the duality between specification and verification, one of the most interesting ISO

GPS concepts, found scarce correspondence in the structure and content of the DGLs knowledge.

DGLs Adoption Process

- In some ways, the moment of the generation of the manufacturing and verification rules was wrong; there was no reason to wait until the determination of the product configuration. The set of hints to consider or actions to perform could be defined at the beginning, during the DGLs setup, independently from the specific product under analysis. Once defined, the configuration of the specific product, the meaningful hints or actions, could be simply selected from the set. An important outcome of these considerations is that it was the first time that the need for a clear distinction between the setup phase of the DGLs and their adoption became clear.
- Given that the DGLs were going to become a large project, the need for an overall architecture and for some sort of roadmap for their adoption arose.

2.4 Third Release of the DGLs. Thinking Big

The development of the third release of the DGLs started from the suggestions summarised in the last paragraph of the previous section. In this case, the main goals were to introduce an overall architecture of the project, to take care of knowledge formalisation and correctness, to introduce a real management of product configuration in terms of parameter quantification, to update the knowledge content, to take care of terminology correctness, and to keep under consideration the customisation/flexibility of the system (Filippi and Cristofolini 2007).

2.4.1 Conceptual Diagram

In this release of the DGLs the conceptual diagram became more complex and articulated. This arose from a deep investigation of knowledge generation, the cause-effect paradigm, the relationships between the various domains and the different pieces of information involved. A multi-storey structure was generated, the DGLs building, with five floors: Compatibility floor, Rules floor, Design domain floor, Manufacturing domain floor, and Verification domain floor, as shown in Fig. 2.12.

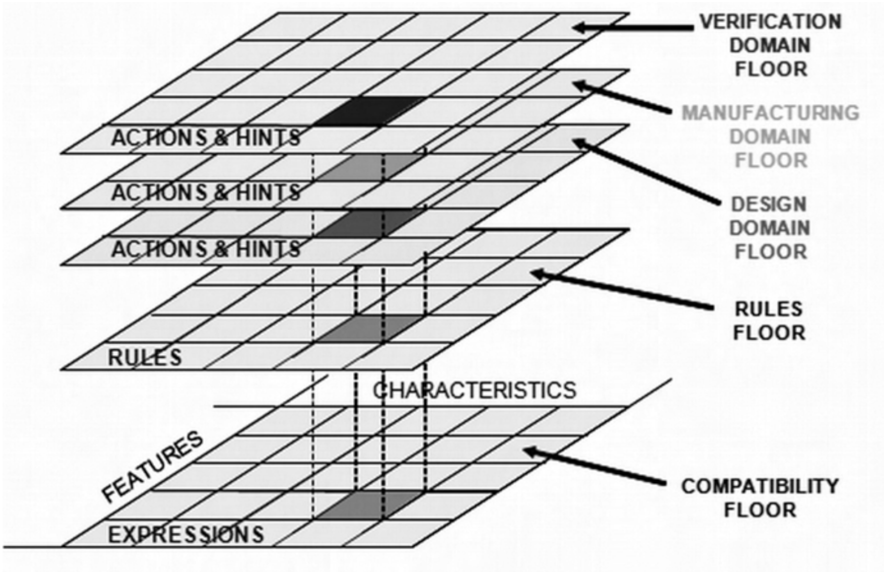

Fig. 2.12 The five-storey DGLs building

The meaning of these information loci is reported hereafter.

- **Compatibility Floor** This floor was used to evaluate the compatibility of the product with the characteristics of the manufacturing and verification processes. Characteristic was the new term used instead of requirement or others. For each product feature — this was the new term used instead of attribute or others — this floor contained all the information needed to calculate a numerical value representing this compatibility.
- **Rules Floor** This floor contained all the rules determined by relating the technological characteristics of manufacturing and verification to the features used to characterise the product. Each rule had an optional brief explanation that justified its presence. This information represented added value for the user who could acquire knowledge of the technologies and use it in future product development. This floor was filled during the setup of the DGLs, before their use. Only during the use of the DGLs, by determining the configuration of a specific product, did the knowledge activation take place; in other words, the selection of the meaningful pieces of information from a general database happened time by time, case by case.
- **Design Domain Floor** This floor contained all the actions related to the design phase of the product. Actions were the suggested way to redesign the product in order to respect the rules. According to the ISO GPS concept of establishing links among design and manufacturing/verification, some actions in the diagram were represented as coupled. For example, there could be one action in the Design domain floor, “Split the model”, and another, linked to it, in the Manufacturing or Verification domain floor, “Merge the split parts”. Moreover,

an estimated value was associated with each action, representing its cost. These values were used during the evaluation of the product compatibility as it will be clear in the following.

- **Manufacturing Domain Floor** The content and meaning of this floor was the same as the previous one but the actions were related to the manufacturing domain.
- **Verification Domain Floor** Same as before, but related to the verification domain.

2.4.2 Knowledge Matrix

In this case, the knowledge matrix reflected exactly the conceptual diagram. There were three-dimensional matrices where each row was related to a feature and each column to a technological characteristic. The cell contents referred to the five floors. The complete structure with the full content of the knowledge matrix is described in the case study.

2.4.3 Roadmap for the Adoption of the DGLs

It was possible to distinguish three separate phases in adopting this release of the DGLs: a Setup phase where the DGLs were addressed to a particular class of manufacturing and verification technologies but not to specific brands and models; a Configuration phase where the DGLs were customised using the data of the available technology; and a Usage phase, the only one depending on the product analysed. Given the articulated structure of the DGLs and the presence of many components with very different meanings and operations, the so-called DGLs roadmap was developed, in order to organise and sequence all the required activities. The case study described hereafter strictly followed this roadmap and the description itself is DGLs roadmap-based, so that the entire sequence should be clear.

2.4.4 Case Study

The spacer shown in drawing format in Fig. 2.13 allowed the testing in the field of this third version of the DGLs. This component, adequately positioned on a base by means of the narrow slide and the overhangs, allows the connection of an upper part using pins inserted in the holes. The goal was to redesign this spacer to optimise its manufacturing with the RP technology named Fused Deposition Modelling — FDM — and its verification with a Coordinate Measuring Machine

— CMM. FDM and CMM technologies will be described in detail later in the case studies related to the adoption of the DGLs-CF; anyway, to go into details with some meaningful examples related to FDM technologies see Jacobs (1995), and for CMM see Bosch (1995).

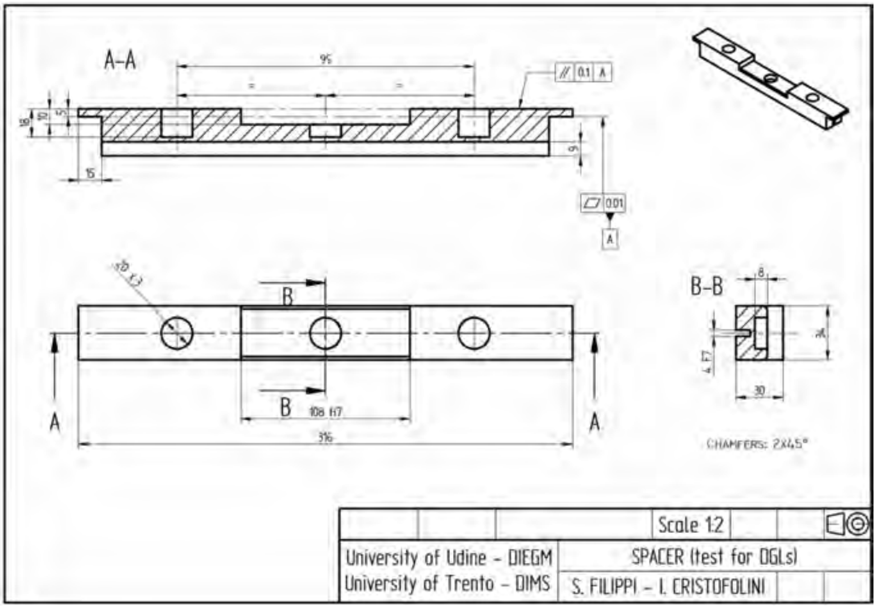

Fig. 2.13 Mechanical drawing of a spacer, the test model for the third release of the DGLs

Setup Phase

Identification of the Technological Characteristics This step analysed the classes of available manufacturing and verification technologies — FDM and CMM — and described them in terms of technological characteristics and related, meaningful parameters. The result is shown in Table 2.3.

Table 2.3 Technological characteristics with related parameters

Label	Characteristic	Parameters
M1	Manufacturing workspace	xMmax, yMmax, zMmax (max dimensions)
M2	Supports	xSmin, ySmin, zSmin, αSmin, αSmax (min dimensions, angles between vertical and walls)
V1	Verification workspace	xVmax, yVmax, zVmax (max dimensions)
V2	Probes	ϕPmin, lPmax (min diameter, max length)

Identification of the Features to Characterize the Product Here the class of the products to be evaluated was analysed and a list of features was generated to characterise them best, with the related parameters and a brief description. The result is shown in Table 2.4.

Table 2.4 Product features with related parameters

Label	Feature	Parameters	Description (optional)
F1	Dimensions	Xmin, Ymin, Zmin, Xmax, Ymax, Zmax (minimum and maximum dimensions)	This feature represents the overall dimensions of the product
F2	Overhangs	α (overhangs angle)	-
F3	Cavities	xCmin, yCmin, dCmax (minimum dimensions and depth)	-

Generation of Rules Each characteristic/feature pair could generate the situation where one or more rules were inserted in the Rules floor of the knowledge matrix. Rules allowed the development of the actions in the upper floors. In this release of the DGLs the attention was focused on overcoming the critical characteristics of the process, while the positive rules were not considered. Table 2.5 shows the rules used in this case study.

Table 2.5 Rules generated from technological characteristics and product features

Label	Origin	Rule
R1	M1 vs F1	Maximum dimensions of the product must be minor than maximum dimensions of the building room
R2	M2 vs F1	Minimum dimensions of the product must be greater than minimum dimensions related to the presence of supports
R3	M2 vs F2	The presence of overhangs must be evaluated considering the need for supports
R4	M2 vs F3	The dimensions and depth of cavities must be compatible with the need of supports
R5	V1 vs F1	Maximum dimensions of the product must be minor than maximum dimensions of the measuring volume
R6	V2 vs F3	Dimensions and depth of cavities must be compatible with the characteristics of the probes

Generation of Expressions and Overall Judgment Criteria to Evaluate Compatibility In correspondence with the entries where rules have been inserted, compatibility values between the product and the technologies were collected. This step generated the expressions to calculate these values. The expressions populated the Compatibility floor of the knowledge matrix. Normalised compatibility values (interval [0..1]) were used. Of course, the quantity/quality of the expressions inserted in the knowledge matrix determined the accuracy of the compatibility evaluation. Together with the expressions, this step set the criterion to express an overall judgment on the product/processes compatibility. Sometimes the sum of all the compatibility values might fit; in other cases the average might be better, and so on. This judgment was particularly important when the user needed to compare different products or different configurations of the same product. In this case study, the overall judgment criterion was set to the average. Table 2.6 shows the expressions used to evaluate the compatibility values in the case study. There is an appendix at the end of the book, showing some details about a couple of them.

Table 2.6 Expressions to compute compatibility values

Label	Origin	Expression	Meaning
E1	M1 vs F1	E1=1 IF Zmax<zMmax AND Xmax<xMmax AND Ymax<yMmax ELSE E1=0 IF Zmax>zMmax OR Xmax>xMmax OR Ymax>yMmax	Compatibility between model maximum dimensions and Workspace dimensions
E2	M2 vs F1	E2=1 IF Zmin>zSmin AND Xmin>xSmin AND Ymin>ySmin ELSE E2=0 IF Zmin<zSmin OR Xmin<xSmin OR Ymin<ySmin	Compatibility between model minimum dimensions and need for supports
E3[a]	M2 vs F2	E3=1 IF α≥αSmax ELSE E3=1-(1/(1+(((α-αSmin)/(αSmax-αSmin))/0.5)4) IF αSmin<α<αSmax ELSE E3=0 IF α<αSmin	Compatibility between model overhangs and need for supports
E4	M2 vs F3	E4=1 IF MIN(Xmin, Ymin)>3•MIN(xSmin, ySmin) ELSE E4=0.5 IF MIN(xSmin, ySmin)<MIN(Xmin, Xmin)<3•MIN(xSmin, ySmin) ELSE E4=0 IF MIN(Xmin, Ymin)<MIN(xSmin, ySmin)	Compatibilities between cavities and need for supports
E5	V1 vs F1	E5=1 IF Zmax<zVmax AND Xmax<xVmax AND Ymax<yVmax ELSE E5=0 IF Zmax>zVmax OR Xmax>xVmax OR Ymax>yVmax	Compatibility between model maximum dimensions and measuring volume
E6[a]	V2 vs F3	E6=0 IF dCmax>lPmax ELSE E6=1 IF MIN(xCmin, yCmin)≥5•ϕPmin ELSE E6=(MIN(xCmin, yCmin)-2•ϕPmin)/3•ϕPmin IF 2•ϕPmin <MIN(xCmin, yCmin) <5•ϕPmin ELSE E6=0 IF MIN(xCmin, yCmin) ≤2•ϕPmin	Compatibility between cavities and probes characteristics

[a] See Appendix for details

At this point, the content of the knowledge matrix related to the Compatibility floor and to the Rules floor was completed; Tables 2.7 and 2.8 show it respectively.

Table 2.7 Part of the knowledge matrix corresponding to the Compatibility floor

<table>
<tr><td colspan="2" rowspan="3">COMPATIBILITY FLOOR</td><td colspan="4">Characteristics</td></tr>
<tr><td colspan="2">Manufacturing</td><td colspan="2">Verification</td></tr>
<tr><td>M1: Manufacturing workspace

xMmax, yMmax, zMmax</td><td>M2: Supports

xSmin, ySmin, zSmin, αSmin, αSmax</td><td>V1: Verification workspace

xVmax, yVmax, zVmax</td><td>V2: Probes

φPmin, lPmax</td></tr>
<tr><td rowspan="3">Features</td><td>F1: Dimensions

Xmin, Ymin, Zmin, Xmax, Ymax, Zmax</td><td>E1=1 IF Zmax<zMmax AND Xmax<xMmax AND Ymax<yMmax ELSE E1=0 IF Zmax> zMmax OR Xmax> xMmax OR Ymax> yMmax</td><td>E2=1 IF Zmin>zSmin AND Xmin>xSmin AND Ymin>ySmin ELSE E2=0 IF Zmin<zSmin OR Xmin<xSmin OR Ymin<ySmin</td><td>E5=1 IF Zmax<zVmax AND Xmax<xVmax AND Ymax<yVmax ELSE E5=0 IF Zmax>zVmax OR Xmax>xVmax OR Ymax>yVmax</td><td>-</td></tr>
<tr><td>F2: Overhangs

α</td><td>-</td><td>E3=1 IF α≥αSmax ELSE E3=1-(1/(1+(((α - αSmin)/(αSmax - αSmin))/0.5)^{4}) IF αSmin< α<αSmax ELSE E3=0 IF α<αSmin</td><td>-</td><td>-</td></tr>
<tr><td>F3: Cavities

MIN(xCmin, yCmin), dCmax</td><td>-</td><td>E4=1 IF MIN(Xmin, Ymin)>3•MIN(xSmin, ySmin)
ELSE E4=0.5 IF MIN(xSmin, ySmin)<MIN(Xmin, Xmin)<3•MIN(xSmin, ySmin)
ELSE E4=0 IF MIN(Xmin, Ymin)<MIN(xSmin, ySmin)</td><td>-</td><td>E6=0 IF dCmax>lPmax
ELSE E6=1 IF MIN(xCmin, yCmin)≥5•φPmin
ELSE E6=(MIN(xCmin, yCmin)-2•φPmin)/3•φPmin IF 2•φPmin <MIN(xCmin, yCmin) <5•φPmin
ELSE E6=0 IF MIN(xCmin, yCmin) ≤2•φPmin</td></tr>
</table>

Table 2.8 Part of the knowledge matrix corresponding to the Rules floor

<table>
<tr><th colspan="2" rowspan="3">RULES FLOOR</th><th colspan="4">Characteristics</th></tr>
<tr><th colspan="2">Manufacturing</th><th colspan="2">Verification</th></tr>
<tr><td>M1</td><td>M2</td><td>V1</td><td>V2</td></tr>
<tr><td rowspan="3">Features</td><td>F1</td><td>R1: Maximum dimensions of the product must be minor than maximum dimensions of the building room</td><td>R2: Minimum dimensions of the product must be greater than minimum dimensions related to the presence of supports</td><td>R5: Maximum dimensions of the product must be minor than maximum dimensions of the measuring volume</td><td>-</td></tr>
<tr><td>F2</td><td>-</td><td>R3: The presence of overhangs must be evaluated considering the need for supports</td><td>-</td><td>-</td></tr>
<tr><td>F3</td><td>-</td><td>R4: The dimensions and depth of cavities must be compatible with the need of supports</td><td>-</td><td>R6: Dimensions and depth of cavities must be compatible with the characteristics of the probes</td></tr>
</table>

Generation of Actions and Related Costs Each rule could suggest actions, referred to design, manufacturing or verification. These actions were labelled as must or hints, as follows. Must represented activities that had to be performed to generate or measure the product; hints were suggestions that the designer, the manufacturer or the inspector could follow to improve the compatibility between the product and the processes. Each must or hint had a qualitative estimated cost associated, expressed in the interval [0..10]. Table 2.9 reports the actions generated by analysing the rules. Each action was classified by domain — design, manufacturing, or verification — and the cost and the link to a coupled action if present were added.

Table 2.9 Actions generated by analysing the rules

Label	Origin	Action	Domain	Cost	Link
A1	R1	Split the model to make dimensions compatible with the workspace	Design	8	A2
A2	R1	Post-process to merge the split part and eventually finish the resulting surface	Manufact.	5	A1
A3	R1	Scale the model making it smaller if A6 has not been performed yet	Design	5	
A4	R2	Over-dimension thin parts	Design	5	A5
A5	R2	Post-process to make over-dimensioned parts thinner	Manufact.	10	A4
A6	R2	Scale the model making it bigger if A3 has not been performed yet	Design	5	
A7	R3	Change the orientation of the product in the workspace to minimise the quantity of required supports	Manufact.	1	
A8	R3	Over-dimension the part considering overall dimensions instead of overhangs	Design	5	A9

Table 2.9 (continued)

A9	R3	Post-process to make the overhangs from the bulk	Manufact.	10	A8
A10	R4	Change the orientation of the product in the workspace to make easier the support removal, evaluating the new orientation in comparison to that eventually resulting from A7. In case of conflict, see A11	Manufact.	1	-
A11	R4	Split the model to avoid the need for supports	Design	8	A12
A12	R4	Post-process to merge the split parts and eventually finish the surface	Manufact.	5	A11
A13	R5	Change the orientation of the product in the CMM volume	Verification	2	-
A14	R6	Avoid requiring the measurement of inaccessible zones of the product	Design	3	-
A15	R6	Tolerance the product so that it is possible obtaining an estimation of the characteristics of inaccessible features indirectly	Design	5	A16
A16	R6	Define an adequate procedure to deduce indirect measurement	Verification	3	A15
A17	R6	Change the orientation of the product in the measuring volume to get better accessibility	Verification	2	-

Now the content of the section of the knowledge matrix related to the Design domain floor, the Manufacturing domain floor and Verification domain floor appeared as shown in Tables 2.10, 2.11 and 2.12 respectively.

Table 2.10 Part of the knowledge matrix corresponding to the Design domain floor

DESIGN DOMAIN FLOOR		**Characteristics**			
		Manufacturing		***Verification***	
		M1	M2	V1	V2
Features	F1	A1: Split the model to make dimensions compatible with the workspace (linked to A2) A3: Scale the model making it smaller if A6 has not been performed yet	A4: Over-dimension thin parts (linked to A5) A6: Scale the model making it bigger if A3 has not been performed yet	-	-
	F2	-	A8: Over-dimension the part considering overall dimensions instead of overhangs (linked to A9)	-	-
	F3	-	A11: Split the model to avoid the need for supports (linked to A12)	-	A14: Avoid requiring the measurement of inaccessible zones of the product A15: Tolerance the product so that it is possible obtaining an estimation of the characteristics of inaccessible features indirectly (linked to A16)

Table 2.11 Part of the knowledge matrix corresponding to the Manufacturing domain floor

MANUFACTURING DOMAIN FLOOR		**Characteristics**			
		Manufacturing		***Verification***	
		M1	M2	V1	V2
Features	F1	A2: Post-process to merge the split part and eventually finish the resulting surface (linked to A1)	A5: Post-process to make over-dimensioned parts thinner (linked to A4)	-	-
	F2	-	A7: Change the orientation of the product in the workspace to minimise the quantity of required supports A9: Post-process to make the overhangs from the bulk (linked to A8)	-	-
	F3	-	A10: Change the orientation of the product in the workspace to make easier the support removal, evaluating the new orientation in comparison to that eventually resulting from A7. In case of conflict, see A11 A12: Post-process to merge the split parts and eventually finish the surface (linked to A11)	-	-

Table 2.12 Part of the knowledge matrix corresponding to the Verification domain floor

VERIFICATION DOMAIN FLOOR		**Characteristics**			
		Manufacturing		***Verification***	
		M1	M2	V1	V2
Features	F1	-	-	A13: Change the orientation of the product in the CMM volume	-
	F2	-	-	-	-
	F3	-	-	-	A16: Define an adequate procedure to deduce indirect measurement (linked to A15) A17: Change the orientation of the product in the measuring volume to get better accessibility

The knowledge matrix started to have a structure so articulated as to suggest the use of some tool to manage the information content, in order to ensure consistency and validity. As what happens in 3D modelling by feature, where any modification to the model must be monitored and validated to keep the model valid (Shah and Mäntylä 1995), or in the DBMS — Data Base Management Systems — where there are different types of integrity checks, here had been hypothesised the presence of a tool helping to assure the validity of the knowledge database during its setup and update. All of this could be automatic, using a sort of consistency monitor based on the application of a set of validation rules to ensure correct data management. These validation rules, simple to be defined, inserted and integrated in the system, could help in increasing the DGLs flexibility. To clarify the role of the monitor, here are two examples of validation rules.

- **Validation Rule 1** For every action in the Design domain floor defined as coupled with another, the corresponding action in the Manufacturing domain floor or in the Verification domain floor must exist and it had to show the same backward link.
- **Validation Rule 2** The expressions to calculate compatibility values must cover all possible situations.

In the end, the hypothesis about the introduction of this consistency monitor never found a real implementation; nevertheless the requirements about the database correctness remain and they will be kept under consideration in future work.

Configuration Phase

Quantification of the Technological Parameters. Given the brands and models of the available manufacturing and verification technologies, the parameter values of the technological characteristics were set as follows, and inserted in Table 2.7:

- xMmax=200 mm, yMmax=200 mm, zMmax=300 mm
- xSmin=2 mm, ySmin=2 mm, zSmin=1 mm, αSmin=45°, αSmax=120°
- xVmax=600 mm, yVmax=600 mm, zVmax=550 mm
- ϕPmin=1 mm, lPmax=20 mm

Usage Phase

Product Characterisation This step was similar to the previous one but here the parameters associated with the product features were set, and Table 2.7 was updated accordingly. The parameter values for this case study were as follows:

- Xmin=4 mm, Ymin=15 mm, Zmin=3 mm
- Xmax=34 mm, Ymax=316 mm, Zmax=30 mm
- α=90°
- MIN(xCmin, yCmin)=4 mm
- dCmax=9 mm

Calculation of the Compatibility Values and Knowledge Activation Given the values of all the parameters involved, expressions generated in step 4 determined the compatibility values for each entry of the knowledge matrix where they were present. Based on these values, the DGLs were able to activate the only pieces of information meaningful for the situation, i.e. actions tagged as must when the compatibility value was equal to zero and hints otherwise, except for the value equal to 1, meaning full compatibility — no need for any must or hints. Table 2.13 reports the compatibility values and the list of the activated actions, classified as must or hints, for this case study.

Generation of the Reconfiguration Packages Must and hints were now aggregated to generate a set of reconfiguration packages where they were arranged in order to avoid discrepancies or repetitions and to allow the users to choose among them. If all the compatibilities resulted in non-zero values, packages contained only hints to improve product compatibility. Each package had two associated costs, referring to the application of the must and the hints respectively, and a value representing the compatibility value obtained after the adoption of the must (if any).

Table 2.13 Compatibility values and activated actions, classified as must or hints

Compatibility value	**Description**	**Activated Knowledge (must and hints)**	**Total cost**
E1=0 (due to y max dimension)	Compatibility between model maximum dimensions and Workspace dimensions	Must: Split the model (Design) Must: Post-process to merge the split part and eventually finish the resulting surface (Manufacturing)	13
		Must: Scale the model making it smaller (Design)	5
E2=1	Compatibility between model minimum dimensions and need for supports	-	-
E3=0.674 (due to the presence of overhangs)	Compatibility between model overhangs and need for supports	Hint: Change the orientation of the product in the workspace to minimise the quantity of required supports (Manufacturing)	1
E4=0.5 (due to x min dimension)	Compatibilities between cavities and need for supports	Hint: Change the orientation of the product to make easier the support removal, evaluating the new orientation in comparison to that eventually resulting from the application of the previous hint. In case of conflict, Split the model (Manufacturing)	1
E5=1	Compatibility between model maximum dimensions and measuring volume	-	-
E6=0.66 (due to x min dimension)	Compatibility between cavities and probes characteristics	Hint: Change the orientation of the product in the measurement volume to get better accessibility (Verification)	2

In this case study the DGLs generated three reconfiguration packages. Table 2.14 shows them, with must and hints distributed over the three domains — design, manufacturing, and verification.

Table 2.14 The set of reconfiguration packages generated by the DGLs

PACKAGE 1	**Must**	**Hints**
Design domain floor	Split the model	-
Manufacturing domain floor	Post-process to merge the split part and eventually finish the resulting surface	Change the orientation of the product in the workspace to minimise the quantity of required supports Change the orientation of the product to make easier the support removal, evaluating the new orientation in comparison to that eventually resulting from the application of the previous hint. In case of conflict, Split the model
Verification domain floor	-	Change the orientation of the product in the measurement volume to get better accessibility
Total costs	13	4
Compatibility value after must application (Average)		1

Table 2.14 (continued)

PACKAGE 2	**Must**	**Hints**
Design domain floor	Scale the model making it smaller Over-dimension thin parts	-
Manufacturing domain floor	Post- process to make the over-dimensioned parts thinner	-
Verification domain floor	-	Change the orientation of the product in the measurement volume to get better accessibility
Total costs	20	2
Compatibility after must application (Average)		1

PACKAGE 3	**Must**	**Hints**
Design domain floor	Split the model Scale the model, making it bigger	-
Manufacturing domain floor	Glue the split parts and eventually finish the resulting surface	-
Verification domain floor	-	Change the orientation of the product in the measurement volume to get better accessibility
Total costs	18	2
Compatibility after must application (Average)		1

User Choice of a Reconfiguration Package and Implementation. Based on costs, resources availability, etc., the DGLs user could choose the package that best fitted the surrounding conditions and proceeded to its implementation. In this case, the chosen package was the number 1 and the model resulting from the application of its must and hints is shown in Fig. 2.14. Figure 2.14a is a screenshot of the FDM workspace setup; Fig. 2.14b shows the generation of the physical prototype of the split parts and, finally, Fig. 2.14c,d are pictures of the verification phase after the gluing action.

2.4.5 Discussion

Positive Outcomes

In this release of the DGLs the conceptual diagram was much better than before. Now it was clear how knowledge was generated, the cause-effect paradigm, the information classification in the different domains, etc. It was possible to extract, consult and print the must and hints related to each domain. For example, inspectors could easily extract the list of the verification actions that were meaningful from their point of view.

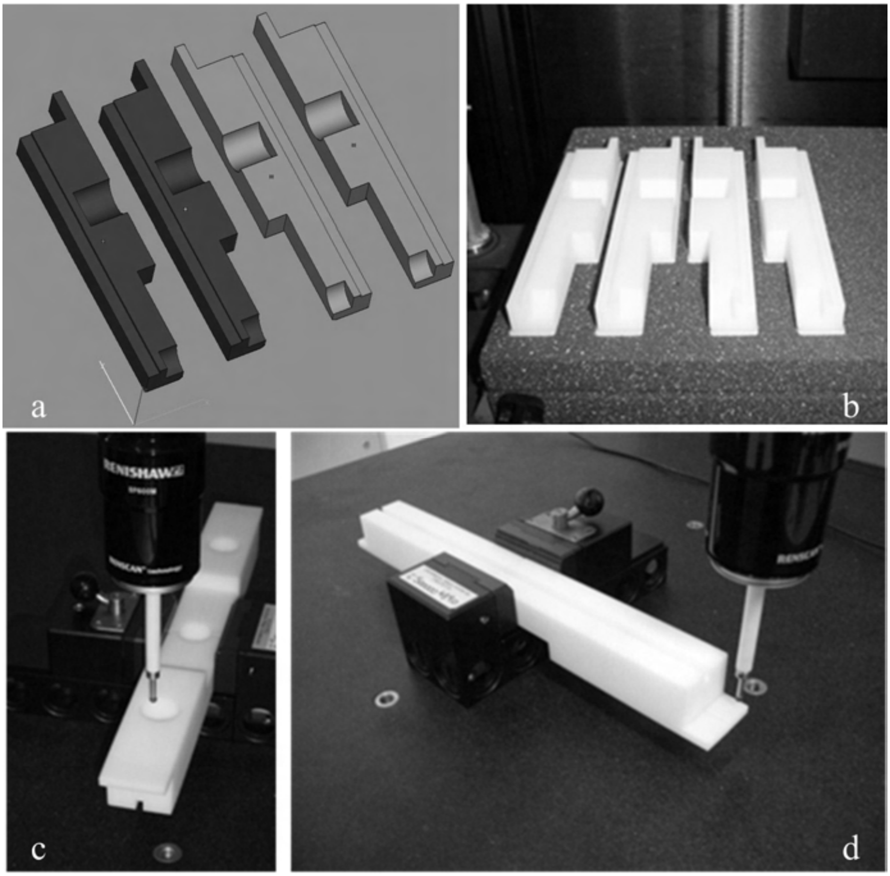

Fig. 2.14 The product adequately modelled and oriented inside: **a** the virtual manufacturing workspace; **b** the real manufacturing workspace; **c, d** the verification workspace

Here rules were not related to the moment when they were applied. So they could be derived in advance from technological characteristics and product features, during the DGLs setup and before the DGLs adoption. This structure let us separate and distinguish clearly these two different phases in using the DGLs. Moreover, the presence of the parameters in the Compatibility floor, and the concept of activated knowledge, made the DGLs a very flexible tool. Changing the available manufacturing or verification technologies required no modifications of the DGLs structure but just some modifications in the parameter values from the point of view of the knowledge content. The consistency monitor concept would have ensured that all of this occurred correctly.

This release of the DGLs better exploited the ISO GPS adoption. For example, the ISO GPS concept of linking design and manufacturing/verification was applied by introducing the links between couple of actions placed on different floors.

Finally, this release of the DGLs allowed the comparison of different product configurations as there was a quantification of the compatibility between the product features and the technological characteristics, together with some quantification associated with the reconfiguration packages.

Relating to the categories of problems and open issues of the previous releases of the DGLs, here something positive has been done about the Conceptual diagram and knowledge organisation, the DGLs adoption process and the ISO GPS adoption. However, the experience described above gave some impressions of the presence of criticisms even of this revised version of the DGLs, and they appear in the following, as usual.

Conceptual Diagram and Knowledge Organisation

- The DGLs building was now clean and it represented quite well the knowledge organisation and the inference process. However some misunderstanding still remained regarding the Compatibility floor and the Rules floor. The compatibility is intrinsically a rule attribute so it should have been better to put these pieces of information on the same floor.

Knowledge Description

- Must and hints were concepts used here in the wrong way. It seemed that actions were classified before knowledge activation and this is a conceptual mistake. This classification made the knowledge description more confused and, in the end, it appeared useless because its meaning was obvious. This is why it disappears in the DGLs-CF.
- Nothing really meaningful has been done here regarding the characterisation of products and processes. Again, the ISO GPS adoption was not exploited from this point of view. For example, tables containing the information about the adoption context for the DGLs were filled using non-homogeneous terminology and this made the inference process hard to perform or, even more, to implement.

Costs

- Here there was a second attempt to consider costs during the redesign and reconfiguration process. Their management appeared quite organic and coherent; however, the big challenge consisted of the determination of them. This topic has not been managed at all in this release of the DGLs. Cost values were set in a relative way only to allow the comparison among the different reconfiguration packages generated at the end of the DGLs adoption process.

Implementation/Automatisms

- The data structures were not optimised for any implementation. Moreover, there was no attempt to highlight potential modules in order to introduce and/or increase the automatisms of the DGLs.

ISO GPS Adoption

- As said before, ISO GPS adoption was not exploited even in this release of the DGLs. One of the most important aspects of the ISO GPS standards is that they suggest a vocabulary for describing the pieces of information. Unfortunately, this aspect was not taken into consideration but it should have been.

DGLs Adoption Process

- Even if the DGLs roadmap was of great help in understanding the knowledge generation and inference, some problems relating to the DGLs adoption process still remained. For example, the generation of the reconfiguration package was an intrinsically iterative process and this was not clear enough and sufficiently highlighted in the DGLs roadmap.

DGLs Architecture

- Two issues started to be really clear from this release of the DGLs: the drawbacks coming from the bottom-up approach of its development and the need for a formalism to describe both the development and the adoption of the DGLs. For sure the DGLs roadmap helped with the comprehension but it was not enough for considering and highlighting the actors involved, the input/output of the phases and of the single activities, the tools used time and time again during the DGLs adoption, etc.

Summary

This chapter has described the work preceding the DGLs-CF development. The starting point has been the desire for generating a DfX method, to be used as the basis for going ahead with some new concepts such as the concurrent redesign and reconfiguration of product and process, with the help of emerging standards such as the ISO GPS. Three releases of the DGLs allowed us to highlight some important issues and to indicate the way ahead for the development of the DGLs-CF. This will be described in detail in the next chapters.

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