2

DRM: A Design Research Methodology

This chapter presents the outline of our methodology and introduces the main stages and concepts. At the end of the chapter, a comparison is made with the few other methodologies that have a similar purpose.

2.1 Introduction

The previous chapter described the two overall objectives of design research as formulating and validating models and theories about the phenomenon of design as well as developing and validating knowledge, methods and tools founded on these models and theories with the aim to improve design, that is, to improve the chances of producing a successful product. This raises a number of important questions:

- What do we mean by a *successful* product?
- How is a successful (or unsuccessful) product *created*?
- How do we *improve* the chances of being successful?

The first question leads to issues such as what the *goals* are and, derived from these goals, what *criteria* should be used to judge success, as these can be used to determine whether our research has been successful. The second question leads to issues such as the identification of the *influences* on success, how these influences interact, and how they can be assessed. Investigating these issues will increase our understanding of design, which is needed to improve it. The third question gives rise to issues related to how this understanding can be used to develop *support* and how this can be evaluated. Evaluation is needed to determine whether the *application* of the proposed support indeed leads to more success as determined by the criteria, *i.e.*, whether our goals have been achieved. Our research methodology intends to address these issues in an integrated and systematic way.

While a methodology should help realise a better planned and smoother research process, thereby increasing the *chances* of obtaining valid and useful results, such outcomes cannot be guaranteed: the nature of a methodology is heuristic, rather than algorithmic. Each researcher has his or her personal background and interests, making each research process unique. A methodology can only *support* this process. The outcome may be better and the topic may be more evenly researched, more rigorous and more reliable, but of course a good solution can be achieved without a methodology (usually at some cost) and a poor result can still be achieved when a methodology is applied (*e.g.*, because of a lack of specialist knowledge in the field of study or of a lack of reflection).

A methodology should be used in a flexible and opportunistic way to be able to adapt to the specifics of the research topic and any interesting avenues that may emerge (see also Section 3.8: general guidelines on doing research).

As stated in Chapter 1, the *aim* of DRM is to help design research become more effective and efficient. The *specific objectives* of DRM are:

- to provide a framework for design research for individual researchers as well as teams;
- to help identify research areas, projects and programmes that are most likely to be academically and practically worthwhile and realistic;
- to allow a variety of research approaches and methods;
- to provide guidelines for systematic planning of research;
- to provide guidelines for more rigorous research;
- to help develop a solid line of argumentation;
- to provide new methods and pointers to existing methods to carry out the stages of the research process;
- to help select suitable methods and combinations of methods;
- to provide a context for positioning research projects and programmes relative to other design research;
- to encourage reflection on the applied approach.

2.2 Methodological Framework

DRM consists of four stages: Research Clarification, DS I, Prescriptive Study (PS) and Descriptive Study II (Blessing *et al.* 1992; Blessing *et al.* 1995). Figure 2.1 shows the links between these stages, the basic means used in each stage and the main outcomes. The bold arrows between the stages illustrate the main process flow, the light arrows the many iterations.

A simple example is used to describe the framework. In the example, the stages are executed in a linear fashion for reasons of clarity. The example is followed by a discussion of the many variations of research that are possible within this framework. Section 2.6 provides a description of the objectives and main concepts of each stage. Details on how to execute each stage and suggestions for methods that can be used can be found in Chapters 4 to 6.

Example

Imagine a research project that starts with the aim of improving the way in which the early stages of the design process are executed, in particular the task-clarification stage. The underlying assumptions of the researchers (partly based on their understanding of design and partly on beliefs) are the following: task clarification is a crucial activity; improving the quality of task clarification will improve the design process; this in turn will result in a better and thus more successful product. Furthermore, they consider the currently available design support ineffective. The researchers decide not to immediately concentrate on their initial idea – the development of a requirement management tool – but to apply a systematic research approach, following the DRM framework shown in Figure 2.1.

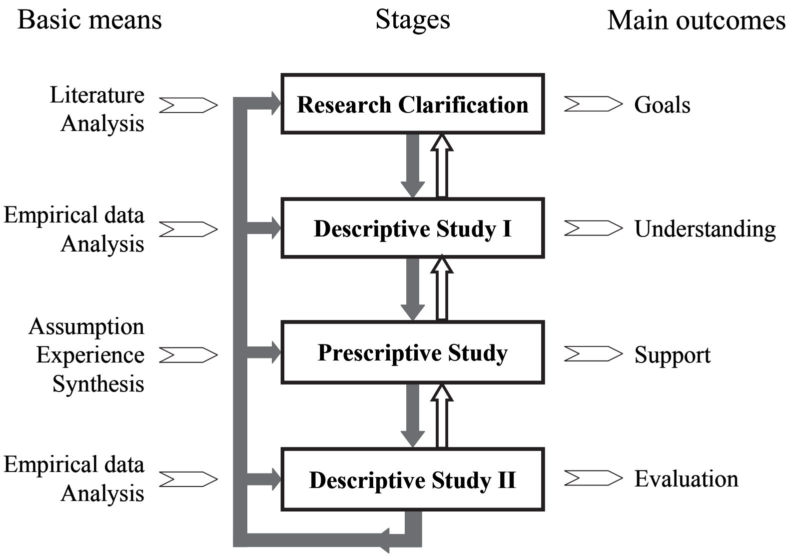

Figure 2.1 DRM framework[5]

In the **Research Clarification (RC)** stage the researchers try to find some evidence or at least indications that support their assumptions in order to formulate a realistic and worthwhile research goal. They do so mainly by searching the literature for factors that influence task clarification and product success, in particular those factors that link the two together. Based on the findings, an initial description of the existing situation is developed, as well as a description of the desired situation, in order to make the assumptions underlying each of the descriptions explicit. The researchers continue to formulate some criteria that could be used as measures against which the outcome of the research, *i.e.*, the support for task clarification, could be evaluated. It becomes clear that criteria for product success, such as 'increase in profit', cannot be used as a measure given the timeframe of the research project, but that 'reduction in time-to-market' could be a possible useful proxy.

In the **Descriptive Study I (DS-I)** stage, the researchers, now having a clear goal and focus, review the literature for more influencing factors to elaborate the

[5] Note that the terminology has changed since the inception of this framework in 1992 (see Preface).

initial description of the existing situation. The intention is to make the description detailed enough to determine which factor(s) should be addressed to improve task clarification as effectively and efficiently as possible. However, they do not find enough evidence in literature to clearly determine these crucial factors, and decide to observe and interview designers at work to obtain a better understanding of the existing situation, before moving on to the next stage and start developing support to address these factors. The analysis of the empirical data reveals the typical characteristics of insufficient problem definition and shows that insufficient problem definition in the task-clarification stage is related to a high percentage of time spent on modifications in later stages of the process. No evidence is found that more time spent on modifications increases time-to-market, but logical reasoning supported by other findings in the literature suggests that this is a plausible assumption. They decide that their understanding, reflected in the description of the existing situation, is sufficient for them to proceed to the Prescriptive Study stage.

In the **Prescriptive Study (PS)** stage, the researchers use their increased understanding of the existing situation to correct and elaborate on their initial description of the desired situation. This description represents their vision on how addressing one or more factors in the existing situation would lead to the realisation of the desired, improved situation. They develop various possible scenarios by varying the targeted factor(s). The researchers decide to focus on improving the quality of the problem definition as the most promising factor to address. Their argument is that this should reduce the number of modifications, which in turn should reduce design time, which eventually should shorten time-to-market and increase product success through increased profit. They now have enough confidence to start the systematic development of a support to improve the quality of problem definition. They use their understanding of the various interconnected influencing factors obtained in the DS-I stage; the well-developed description of the desired situation; as well as their experience in developing design support. To help them develop the support in a systematic way, the researchers choose to follow a design methodology. After a task clarification and conceptual design stage, they have the concept of a software tool (the intended support) that is expected to encourage and support problem definition as intended. They decide to focus their realisation efforts on the core of this support, as this should be sufficient to be able to evaluate the concept and verify the underlying assumptions. A first evaluation of this actual support shows that it has been developed correctly. Whether the support has the desired effects, however, is not clear yet, because of the many assumptions upon which the description of the desired situation and the development of the support have been based.

The researchers proceed to the **Descriptive Study II (DS-II)** stage to investigate the impact of the support and its ability to realise the desired situation. They undertake two empirical studies to gain an understanding of the actual use of the support. The first study is used to evaluate the applicability of the support. The main question is whether the software can be used to encourage and support high-quality problem definition. The second study is used to evaluate the usefulness, *i.e.*, success of the software, based on the criteria developed earlier. The main questions are whether less time was spent on modifications, and whether this eventually reduced time-to-market. The studies show that the support is applicable, but that the usefulness is less than expected. The researchers find that this is partly caused by the fact that the support actually developed includes only part of the support intended. They observe several effects they had not anticipated, such as the large amount of time needed to keep the problem definition up-to-date. The researchers conclude that their concept is promising, but that further investigations of the existing situation are needed and that the picture of the desired situation needs to be adapted accordingly before the tool can be improved and recommend a revisit of the DS-I stage.

Iterations and Variations

As we indicated at the beginning of this section, the example does not show the many iterations and the parallel execution of stages that are part of reality. Neither does it show that the starting point can be in any of the stages, and that it is possible, in an individual project, to concentrate on one or two stages only. The example is simplified and only intended to clarify the main flow of the process.

DRM is not to be interpreted as a set of stages and supporting methods to be executed rigidly and linearly. The negative effects of doing so are well known from the application of design methodologies. Fricke, *e.g.*, observed that designers who tried to follow a design methodology step by step in a rigid fashion, produced designs of a lesser quality than those following a goal-directed but flexible approach (Fricke 1993a). The design process and the application of its methods are to a certain extent opportunistic (Bender 2004) and have to be adapted to the situation at hand (Zanker 1999). Iterations take place to increase understanding, as well as when understanding has increased (Chakrabarti *et al.* 2004) and stages are executed in parallel for a more efficient process (known as Concurrent or Simultaneous Engineering).

The same is true for the research process. As discussed in Antonsson (1987); Reich (1995), science does not often proceed in the linear, logical fashion suggested by its methodologies, although reports often suggest this. Iterations are commonplace within each stage. The results of an empirical study in the DS-I stage may reveal the need for further, erstwhile unplanned, studies, each enriched by the knowledge gained in the previous studies. Iterations are also common between stages. In the RC stage, it might be necessary to carry out some exploratory study (DS-I) to clarify the research goals and to develop a research plan, when little is known about the phenomenon of interest. While developing support (PS stage) an additional DS-I might be necessary to obtain more information about certain aspects of the context in which the support is to be implemented. And the results of the DS-II stage will usually warrant a revisit of one of the earlier stages.

To avoid too many unexpected iterations between stages, it is useful to plan stages to be partly executed in parallel. For example, it is necessary to start planning the evaluation of a support (DS-II) during and not after the development of this support (PS) in order to be able to determine which parts of the support need to be realised in order to do the desired evaluation. An example of parallel execution of stages can be found in Bracewell and Shea (2001) shown in Figure 5.14. The number and extent of iterations and the degree to which stages are run in parallel depend on the focus and constraints of a particular research project or programme.

2.3 Types of Research Within the DRM Framework

DRM as presented in this chapter is essentially comprehensive. As discussed earlier, it is not assumed, however, that a specific research project will necessarily include each stage, or undertake each stage in equal depth. In some cases, the literature provides sufficient material for a particular stage; in other cases, a research project may focus on only one stage for an in-depth study, because of time restrictions or because the project is part of a larger programme.

Figure 2.2 lists what we believe are the seven possible types of design research based on whether the state-of-the-art with respect to a particular stage requires a comprehensive study or whether a **review-based study** is sufficient. The research questions and hypotheses, and the available time and resources will determine the type of research to be undertaken. A review-based study is based only on the review of the literature. A **comprehensive study** includes a literature review, as well as a study in which the results are produced by the researcher, *i.e.*, the researcher undertakes an empirical study, develops support, or evaluates support. An **initial study** closes a project and involves the first few steps of a particular stage to show the consequences of the results and prepare the results for use by others. Each of the seven types will be discussed in more detail in Section 3.5.

Research Clarification	Descriptive Study I	Prescriptive Study	Descriptive Study II
1. Review-based →	Comprehensive		
2. Review-based →	Comprehensive →	Initial	
3. Review-based →	Review-based →	Comprehensive →	Initial
4. Review-based →	Review-based →	Review-based → Initial/ Comprehensive ←	Comprehensive
5. Review-based →	Comprehensive →	Comprehensive →	Initial
6. Review-based →	Review-based → ↑	Comprehensive → ↑	Comprehensive
7. Review-based →	Comprehensive → ↑	Comprehensive → ↑	Comprehensive

Figure 2.2 Types of design research projects and their main focus. (Iterations omitted)

The following assumptions were behind the selection of these seven types of research:

- Each project should start with a clarification of the research (RC stage) by reviewing the literature, to determine the aim, focus and scope of the research project.

- Any Comprehensive DS-I should be followed by an Initial PS to at least suggest how the findings could be used to improve design. An exception is Type I, in which the focus of the DS-I is on identifying criteria of success that can be used in design research. This type of research is followed by any of the other types of research.
- The comprehensive development of support (Comprehensive PS) should at least be based on a review of descriptive literature (Review-based DS-I), and be followed by an Initial DS-II to evaluate the resulting support. Many research projects we have seen end with the realisation rather than an evaluation of the support.
- A Comprehensive DS-II (evaluation) should be based on a Comprehensive PS or a Review-based PS to identify the background of the support to be evaluated, and at least be followed by an indication of how the support is to be improved (Initial PS).
- Each project should take into account all the stages of DRM, *i.e.*, past and future research have to be considered. Research projects and programmes are always contributions to a larger knowledge domain. It is therefore important that existing knowledge (results of past research) is referred to and used where appropriate, and that the results of one's own research are prepared in a way that allows others to use the gained knowledge in future projects.

The first four types of research project in Figure 2.2 focus on one particular stage, and are very suitable for PhD projects, although we have seen very few projects of Types 1 and 4. Types 5 and 6 cover two stages in-depth. The initial plans of PhD projects often aim for these types of research, but, as we observed, the time and resources required are often underestimated and the projects mostly end as Types 2 and 3, respectively. Type 7 requires three stages to be undertaken in-depth. This is more common for the work of a research group or when a problem with a very specific scope is addressed.

Our example represented a research project of Type 7. Had the literature review provided enough evidence to support the assumptions of the researchers and sufficient understanding to directly focus on the development of the support (PS stage), there would have been no need to do an empirical study in DS-I. This would then have been a project of Type 6. Had the researchers known that existing support was ineffective, but not known the exact problems, they could have decided to focus on a systematic evaluation of the use and usefulness of existing support (DS-II) and the development of suggestions for improvement (PS). This would result in a research project of Type 4. Other considerations, such as time constraints, would have resulted in other types of research.

2.4 Representing Existing and Desired Situations

As illustrated in the example, descriptions of the existing and the desired situation play a central role in DRM. We propose the use of – what we call – **networks of influencing factors** to describe the situations. We distinguish two types of networks of influencing factors, to describe the two situations relevant for DRM. The **Reference Model** represents the existing situation in design and is the reference – hence its name – against which the intended improvements are benchmarked. The **Impact Model** represents the desired situation and shows the assumed impact of the support to be developed. The models developed in the RC stage (see our example) describe the initial image of these situations and hence are called **Initial Reference Model** and **Initial Impact Model** (see Chapter 3 for details of developing these Initial Models). A full Reference Model is developed in the DS-I stage (see Chapter 4 for details) and a full Impact Model in the PS stage (see Chapter 5 for details).

A *model* is a likeness of something that exists in reality, but restricted to some particular aspects of this reality. Which aspects are represented depends on the purpose of the model, *i.e.*, on its intended use. Models are used in science to provide conceptual organisation. They show the significant relationships between the concepts or attributes, and thus highlight the aspects that are the focus of the research. Models are not theories, but they can be used to represent a theory.

2.4.1 Graphical Representation

This section summarises the main characteristics of the graphical representation we developed to present these models, using a Reference Model (see Figure 2.3) developed for the example discussed earlier. This Reference Model represents the level of understanding of the existing situation the researchers had at the end of their DS-I stage.

Figure 2.3 has to be interpreted as follows. The nodes represent influencing factors. An **influencing factor** (or **factor** for short) is an aspect of the existing situation (or the desired situation in the case of an Impact Model) that influences other aspects of this situation, *e.g.*, 'the quality of the product' or 'the satisfaction of the customers' influence 'market share'. Influencing factors can cover all of the facets of design shown in Figure 1.1 and can come from the literature or other sources, such as assumptions, experience, research goals, focus, questions and hypotheses. A particular situation is represented by the factors that influence this situation and the links between these factors.

An influencing factor is formulated as an **attribute** of an **element** that is considered relevant and that can be observed, measured or assessed, *i.e.*, for which a so-called operational definition can be formulated (see Section 4.5.2). An example is 'quality *(attribute)* of problem definition *(element)*', see Figure 2.4.

The addition of the attribute is essential. 'Problem definition', *e.g.*, cannot be an influencing factor as it only describes the element. This introduces ambiguity: the researcher could mean 'time spent on problem definition', 'quality of the problem definition', 'knowledge about the source of the problem definition', *etc*. Each of these would be linked differently in the network: 'time spent on problem definition' influences the 'overall design time'; 'quality of problem definition' influences 'reliability of the product'; *etc*. The attribute thus determines the link to other factors and hence has to be made explicit.

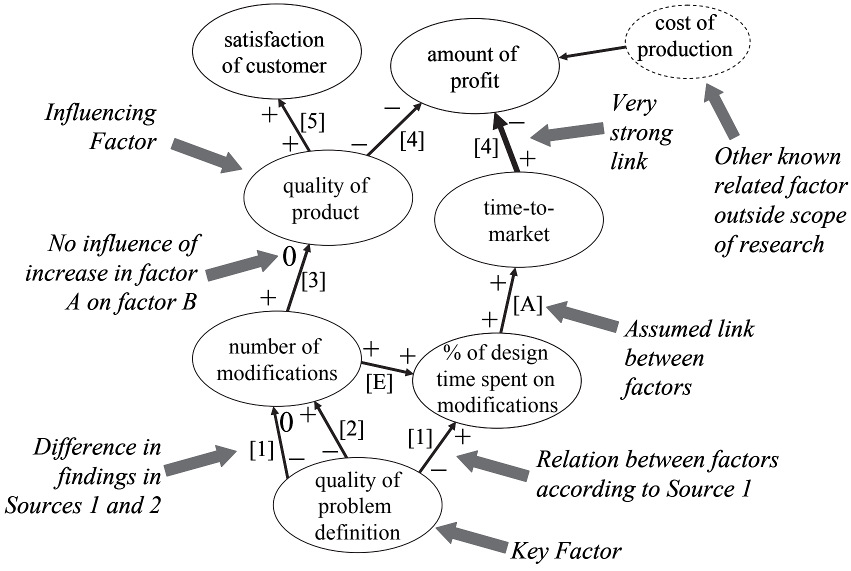

Figure 2.3 A Reference Model representing the – partly assumed – existing situation

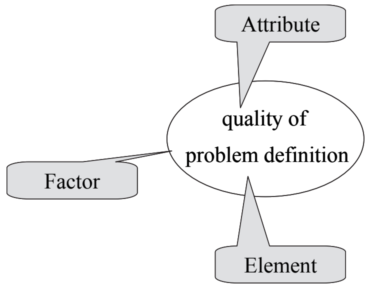

Figure 2.4 Factor, attribute and element

Key Factors are those influencing factors that seem to be the most useful factors to address in order to improve an existing situation. These are considered the core factors or the root causes. The Key Factors are addressed directly by the support. In our example, the researchers decided on the basis of their investigations that addressing the factor ‘quality of problem definition’ would be the most promising approach to improve ‘product quality’.

Attributes have **values**:

- Values can be qualitative, such as ‘high’ and ‘poor’, or quantitative, *e.g.*, ‘20’, ‘larger than 20’, ‘between 10 and 30’, depending on the definition used in a particular study.
- The existing or desired value of an attribute is attached to a link between factors by means of a ‘+’, ‘–’, or ‘0’ sign. For example, a ‘–’ next to the link and near the factor ‘amount of profit’ indicates ‘low’ profit or, depending on the definition, profit ‘less than 20%’.

- Values should not be included in the description of the factor in the node. Thus 'poor problem definition' is not a correct formulation for a factor. The first reason is that including the value (poor) rather than the attribute (quality) introduces ambiguity: it is not clear whether poor refers to poorly written, poor contents, *etc*. The second reason is that including the value in the node does not allow multiple, differing statements to be represented using the same node. An example are the statements related to 'quality of product' in Figure 2.3; using 'poor quality of product' as factor, based on the link to 'amount of profit' (statement [4]) would not have allowed the statement labelled [5] to be represented as this refers to 'high product quality'.

The **links** between factors show how the factors influence or are desired to influences each other, *i.e.*, they represent explicit statements about the existing or desired situation.

- The combination of '+', '–' and '0' signs at the ends of a link describe how the value of the attribute of the factor at one end relates to the value of the attribute of the factor at the other end. Figure 2.3 represents, *e.g.*, that a poor quality of problem definition (–) relates to high percentages of time spent on modifications (+), and that a large number of modifications (+) was found to have no effect on the quality of the product (0).
- If the link is known or assumed to be a causal link, this is indicated with an arrow (→) from cause to effect.
- If a link exists between three or more nodes, *e.g.*, two factors *together* affect another factor, the links near the affected factor are connected and a single value is placed near the connection, see Figure 3.6 for an example.
- If certain factors are known to influence a factor in the network, but are themselves outside the scope of the research project, these factors are drawn differently, as illustrated by the factor 'cost of production' in Figure 2.3. Acknowledging the effects of such factors indicates awareness of the researcher of other possible influencing factors and supports the search for alternative explanations for research findings.
- Statements that are found in the literature cannot simply be reversed: if high costs lead to reduced sales, this does not imply that low costs lead to high sales. The latter would be an assumption. It is important to base the Reference Model on the original statements, even if this implies a non-continuous line of argumentation (as, *e.g.*, shown by the in- and outgoing links of the factor 'quality of product' in Figure 2.3). The Reference Model represents the current understanding as-is. Assumptions can be added that differ from the original statements, as long as they are labelled as such. The Impact Model, in describing the desired situation, provides the freedom to change statements, but here too, these have to be marked as assumptions.
- It is useful to place the nodes such that the main cause and effect chains are easily seen, for example by placing these from bottom to top, as in Figure 2.3, or from left to right.

Every link is labelled with the source(s) of the statement(s) it represents, using the following abbreviations:

- [X]: the statement was published in the reference numbered X;
- [A]: the statement is an assumption;
- [E]: the statement is based on experience of the stakeholders;
- [O]: the statement is based on own investigations;
- [?] : it is not known whether a link exists.

If contradicting or differing sources are found, these can be represented by drawing a link for each source, each with its own sign-combination as shown in Figure 2.3 between 'quality of problem definition' and 'number of modifications'.

If the literature provides statements that differ from what was assumed or experienced, it might still be useful to keep the links labelled [A] and [E], and add a new link reflecting the statement from the literature. This is particularly true for statements based on experience. The difference between the statement in the literature and experience might be due to a difference in context in which the statements were obtained. There could be difference in batch size, type of company, novelty of the product, subjects involved in the study, *etc*. If such a factor is causing a difference, it can be considered a relevant influencing factor and thus added as a node. The model can be enriched by giving each link an appropriate width to represent the amount of evidence available or the relative strength of one link compared to another. Figure 2.3 shows that according to reference 4 'time-to-market' has a much stronger influence than 'quality of the product' on 'amount of profit'.

Summarising the above, a statement about the existing or desired situation can thus be modelled as two or more nodes representing the factors involved, connected by a line that is marked at either end with the values of the attributes of the factors to represent the details of their relationship. In the case of a causal link, the line becomes an arrow, pointing at the effect. The link is labelled with the source of the statement. Figure 2.5 shows our modelling terminology using the graphical representation of a statement from the literature source 1 stating that a "high product quality has a positive effect on customer satisfaction".

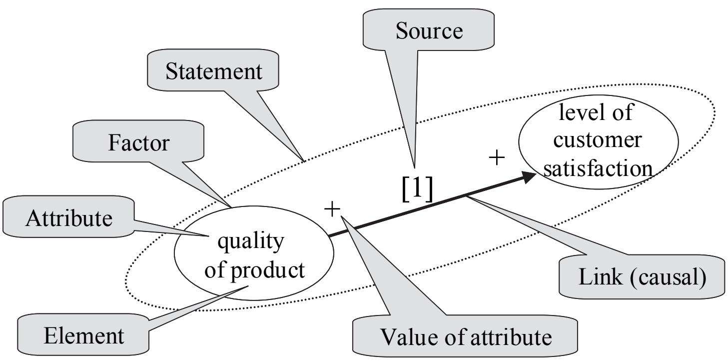

Figure 2.5 Graphical representation of a statement and associated modelling terminology

Note that the models, as we use them in this book, represent statements in a rather qualitative way. Some sources provide statements that are quantitative, including *e.g.*, mathematical equations linking two factors. These details can be added to the model, but care has to be taken not to overload the figures and obscure the overview they are intended to provide. A combination of overview model and partial models can be a useful way to convey details.

In the course of the research process, nodes and links might have to be added, removed, modified or 'opened up' as understanding grows. For example, when the factors that constitute 'level of creativity' have been identified as 'level of novelty" and 'degree of usefulness' (Chakrabarti 2006), or when the factors that cause the link between the "quality of problem definition" and "number of modifications" used in Figure 2.3 have been identified. The opposite might also be useful: to aggregate nodes and links into (new) higher level factors to support explanation or to 'collapse' the model temporarily to provide an overview.

2.4.2 From Reference Model to Impact Model

The Reference Model can be very similar to the Impact Model. An example is a Reference Model of the behaviour of designers in successful projects. Without much editing, it might be possible to create the Impact Model as a basis for developing a set of guidelines for good practice. In most instances, however, the Impact Model cannot be derived directly from the Reference Model. As discussed earlier, the existing situation usually represents a problematic situation that we wish to understand and then improve through the introduction of support. The desired situation is supposed to be different. Hence the model of the desired situation, *i.e.*, the Impact Model, has to be *generated* on the basis of the Reference Model.

Compared to the Reference Model, the Impact Model includes the support and the desired, expected, effects. This may require the introduction of new nodes and links, *e.g.*, auxiliary effects of the use of the support; the removal of existing ones, *e.g.*, those that are no longer relevant, once the support has been introduced; and the changes to the values of certain attributes.

These modifications usually require the introduction of assumptions, because there may be no available evidence of their validity. It is very important to make these assumptions explicit, so that the reasoning behind the Impact Model can be traced and judged. For example, even if a poor quality of the product reduces the amount of profit (the existing situation, shown in Figure 2.3), this does not necessarily imply that high product quality results in large profit (the desired situation). The latter remains an assumption and the corresponding link should be indicated as such in the Impact Model.

Figure 2.6 shows the Impact Model developed for our example on the basis of the Reference Model shown in Figure 2.3. The links have been modified to represent the desired effects. The links that do not have an effect in the current situation have been removed and replaced with links that are assumed to be brought into existence when the support is used. For example, the link between 'number of modifications' and 'quality of product' is removed. Instead, the latter is assumed to be influenced by the 'quality of design evaluation', which is influenced by the 'quality of problem definition'.

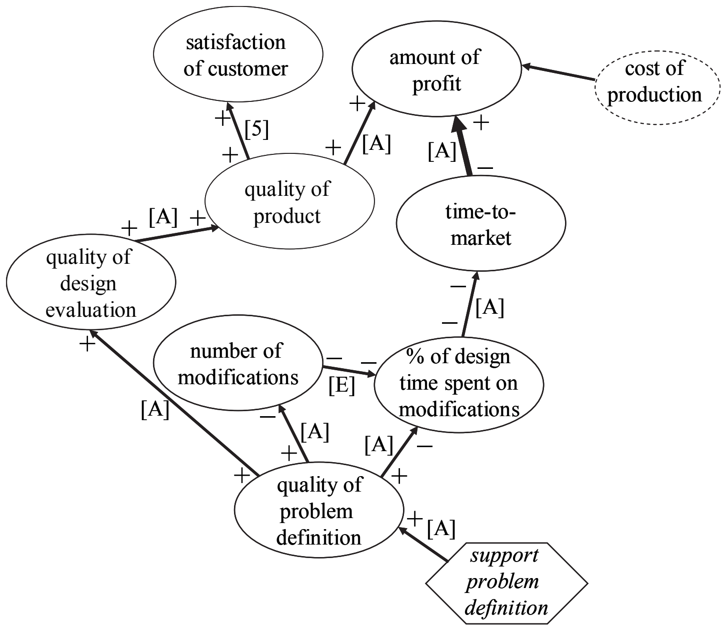

Figure 2.6 An Impact Model, representing the – partly assumed – desired situation after the introduction of the support (represented as an hexagonal element)

In Figure 2.6 the *support* is represented as an hexagonal element to distinguish it from the factors shown in ovals. The label used is the function of the support, *e.g.*, 'support problem definition'. The support is currently linked to the Key Factor, 'quality of problem definition' in the above figure, by a causal link that has no sign at the support end. This means that at this stage, the details of the support are unknown: all we envisage is that the desired effect of the support is to increase the quality of problem definition. As the support is developed further, the Impact Model will be elaborated based on the support's functionality, concept, implementation, introduction, customisation, use and maintenance, which may introduce new factors and links or modify existing ones.

Setting up a graphical representation of the existing and the expected situation in the form of Reference and Impact Models structures findings and clarifies thoughts. The resulting models help:

- to improve understanding by linking various findings and making explicit for which links evidence exists and which ones are based on assumptions;
- to identify realistic research areas and goals, and suitable criteria for judging the results;
- to illustrate and clarify the line of argumentation that shows the relevance of the research and the research approach;
- to determine whether the level of understanding is sufficient to develop support for improvement or whether too many assumptions are involved;
- to identify the factors to be addressed by the support (Key Factors);

- to illustrate one's vision by making explicit the expectations about the desired situation;
- to illustrate and clarify the line of argumentation for developing specific support;
- to encourage discussion and reflection on the existing and desired situation.

Unfortunately, the literature thus far shows very few attempts to draw up networks of influencing factors. A notable exception is Frankenberger (1997), see also Appendix C.4, Figure C.13. Our students found developing Reference and Impact Models to be a powerful method to clarify their thoughts, structure their understanding and reveal their assumptions. In our opinion, developing such models as a research community would reveal our current understanding of design and could act as an important basis for future research (Blessing 2003).

2.5 Success Criteria and Measurable Success Criteria

For a research area, such as design research, with the ultimate aim of improving a situation, formulating criteria for success is essential to be able to determine whether the results help achieve this aim.

Criteria are used to be able to focus the investigation of the existing situation; to assess the contribution of the findings of such investigations to the research goal; to focus the development of support on the most relevant factors; to plan the appropriate evaluation; to focus the realisation of the support on this evaluation; and to assess the evaluation results. That is, criteria are needed to be able to judge the outcome of the research against the research goals.

We define a **criterion** as the desired value of the factor the research project sets out to understand and/or influence as described in the research goal. In our example, the goal was to develop support to reduce time-to-market: the Criterion with which to judge the support resulting from this research project is thus 'short time-to-market'. A criterion can be relative or absolute, qualitative or quantitative. If a research goal refers to several factors, several criteria have to be formulated. Note that the research goals and criteria we discuss here only relate to one of the possible research outcomes, namely the support. Other criteria are needed to judge the scientific quality of the research.

A **preliminary set of criteria** has to be defined during the RC stage, since the choice of criteria will strongly influence the research approach and methods. We found it important to distinguish between Success and Measurable Success Criteria, although it might not be possible to make this distinction until more understanding has been obtained in the DS-I stage.

Success Criteria relate to the ultimate goal to which the research project or programme intends to contribute. These criteria usually reveal the purpose of the research and the eventual, expected contribution to practice. In our example, this was an 'increased amount of profit'.

In the Reference and Impact Models, Success Criteria relate to the **Success Factors**. These are the factors at 'the top' of the network, *i.e.*, at the end of the cause–effect chains that provide the justification of the research. The desired values of the Success Factors are taken as Success Criteria. In Figure 2.3 the potential Success Factors are ‘satisfaction of customer’ and ‘amount of profit’, of which the latter was chosen. Had the reason for that project been that customers were not satisfied because products were unreliable, ‘satisfaction of customer’ would have been the more suitable Success Factor. These choices clearly affect the focus of the research and the means of evaluation.

Success Criteria can relate to any of the facets of design (see Figure 1.1), but usually refer to long-term effects of the research, most of which can only be observed after the product has been produced and introduced into the market. Success Criteria we found in the literature include criteria as varied as: increased sales volume, return on investment, improved company image, optimal exploitation of company competences, increased competitive strength, sustainable development, improved team performance, reduced lead-time and improved product development process.

The definition of success is still a topic of research, as many factors influence success. As a consequence, there are no established metrics to measure success. Furthermore, even if the above-mentioned criteria were established as metrics, they would generally be difficult to apply within the timeframe of a research project. In our example, the duration of the research project makes it impossible to observe an ‘increase of the amount of profit’, even if the support were able to generate such an effect.

What is needed in such cases are **Measurable Success Criteria**, *i.e.*, criteria that are linked to the chosen Success Criteria and can be applied to judge the outcomes of the research, given the resources available within the project or programme. The factors whose desired values are taken as Measurable Success Criteria are the **Measurable Success Factors**. It is important to note that the term *measurable* refers to the possibility of measuring the criteria during the project, and not to the nature of the methods to assess the fulfilment of the criteria, *i.e.*, both qualitative and quantitative research methods can be used.

When it is not possible to use Success Criteria as Measurable Success Criteria, Measurable Success Criteria should be chosen such that they can serve as reliable *indicators* (also called *proxies*) for the Success Criteria. The link between Measurable Success Criteria and Success Criteria is assumed to exist (preferably based on existing evidence, otherwise on reasoning) and is therefore not evaluated in the research project. Therefore, it is important that the Measurable Success Factors are chosen such that these are as close as possible to the Success Factors, *i.e.* the link should be as direct and strong as possible. In this way, the likelihood, that the Success Criteria are fulfilled when the Measurable Success Criteria are fulfilled, is high. In our example, ‘time-to-market’ was chosen as the Measurable Success Factor, as this factor has the strongest link to the Success Factor ‘amount of profit’ (see Figure 2.7).

More than one Success Factor and one Measurable Success Factor may be chosen. In the example, ‘quality of product’ could have been a second Measurable Success Factor. The reasons for not choosing this factor were that it was considered too difficult to assess within the timeframe of the project, that its link with ‘amount of profit’ was not very strong, and that the literature had shown no link with the number of modifications.

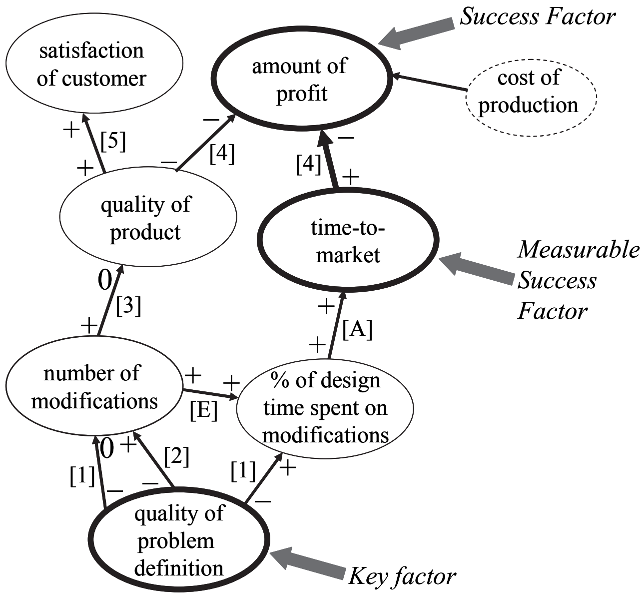

Figure 2.7 The chosen Success and Measurable Success Criteria as well as Key Factors for the Reference Model shown in Figure 2.3

The chosen criteria are transferred to the Impact Model shown in Figure 2.6, to identify the factors and links on which to focus the PS stage and in particular the evaluation in DS-II. During the course of the research project, it may be necessary or desired to select other criteria. In general, the Success Criteria remain relatively static. In many cases, the Measurable Success Criteria are redefined as understanding increases and specific support is developed. In our example, it was decided not to change or add criteria, but to leave out one part of the network in the evaluation as this part was considered not sufficiently influential. The result is shown in Figure 2.8.

The links between the criteria and the factors that the research is addressing can be very complex and the definition of success and suitable performance measures is still a topic of debate and investigation, see, *e.g*., Duffy (1998). However, these should not be reasons for not making these links explicit: assumptions can be introduced where evidence is missing. It is often necessary to piece together bits and pieces found in separate studies to form the overall argument linking the two (sets of) criteria. In some cases, it may be necessary to investigate the links between Success Criteria and Measurable Success Criteria, or part of it, as a study in its own right. This would be a project of Type 1 (see Figure 2.2).

We found that 'amount of sales', 'amount of profit' and 'return on investment' are the commonly used Success Factors in design research that used interviews and surveys in an industrial context. Success and Measurable Success Factors are (nearly) identical. In laboratory research, common Measurable Success Factors were 'product quality' – defined using the level of fulfilment of technical requirements – and 'design time' – defined using the 'time spent to solve the given design task'. The links between these Measurable Success Factors and the Success Factors, *e.g*., that 'product quality' influences 'market success', were partly derived from the literature and partly assumed. In these studies, the distance between the Measurable Success Factors and the Success Factors is large and the link much weaker. In such cases, it is particularly important to make the assumptions explicit and ensure that the claims are realistic.

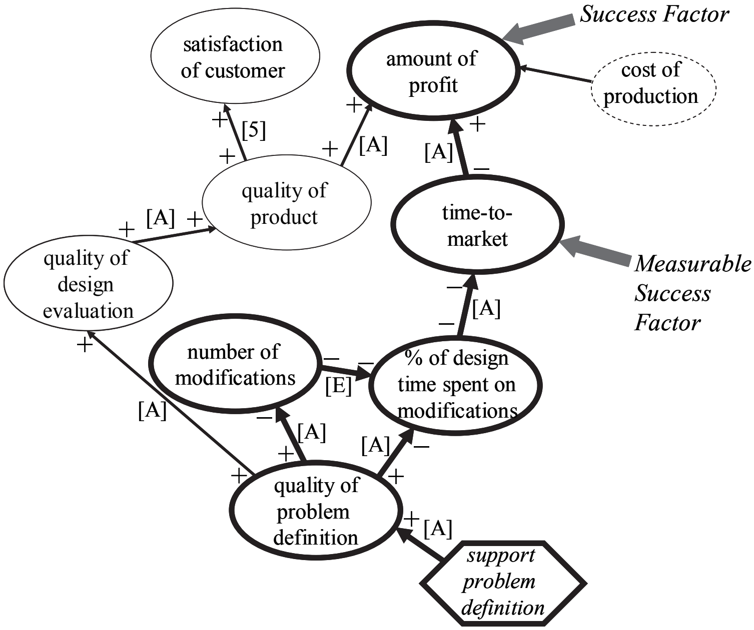

Figure 2.8 The Impact Model indicating the focus of the evaluation of the support

2.6 The Main Stages

In this section, the status of design research with respect to each of the four stages in DRM is presented, as well as their objectives and main deliverables. As to how to proceed in each of the stages is the subject of Chapters 4 to 6.

2.6.1 Research Clarification (RC)

In many research publications, the goals of the research projects refer to the improvement of design practice, *e.g*., reducing lead-time or improving product quality. However, we found very few publications that provided evidence of a link between the stated goals and the actual focus of the research project, *e.g*., improving communication between project members. The line of argumentation from the factors that are studied or addressed, to the factors mentioned in the goal, shows big gaps and is full of assumptions. In general, the goal is not used as the criterion against which the results of the research are judged: the relevant factors are often not even mentioned in the final section or chapter. As a consequence, little evidence exists that the goal has indeed been achieved. Often the reason is a practical one: the timescale of a research project does not allow an improvement of the effectiveness to be measured. Another reason is that the goals are often unrealistic for a single project: only few of the large number of interconnected factors can be addressed and therefore only a limited effect can be achieved.

Another issue is that if the research outcome is judged, the criteria are not made explicit and often seems to be based on assumption rather than evidence. Samuel and Lewis (2001) commented in a similar way on the lack of performance metrics in many studies. Take for example the oft-mentioned goal 'to improve the effectiveness of the design process'. In most cases, the terms are not defined to such a level that they could be used as criteria. What is effectiveness? What is a 'measure' of effectiveness? What type of design process is considered? What part of the design process is of interest? What is improvement: relative to what or with how much? For example, the term 'improve' in a goal has a considerable effect on the evaluation of the support: 'improve' is a relative term. In order to determine whether an improvement has been made, it is necessary to be able to compare the situation before and after the support has been introduced, or to compare situations with and without the support.

We have met many research students that aim, even for some years, at goals and criteria that are too abstract or too long-term, resulting in objectives, research questions and a project plan that are unrealistic. The RC stage intends to support researchers formulating a clear, challenging but realistic Overall Research Plan.

The objectives of the RC stage are:

- to identify the goals that the research is expected to realise; the focus of the research project; the main research problems, questions and hypotheses; the relevant disciplines and areas to be reviewed, and the area in which the contribution is expected;
- to develop Initial Reference and Impact Models, *i.e.*, an initial picture of the existing and of the desired situation;
- to identify a preliminary set of Success Criteria and Measurable Success Criteria against which to evaluate the outcome of the research;
- to provide a focus for the DS-I stage in finding the factors that contribute to, hinder or prohibit success;
- to help focus the PS stage on developing support that addresses those factors that are likely to have the strongest influence on success;
- to provide a focus for the DS-II stage for evaluating the effects of the developed support against the goals of the research.

The deliverables of the RC stage are:

- current understanding and expectations:
  - Initial Reference Model;
  - Initial Impact Model;
  - Preliminary Criteria.

- Overall Research plan:
  - research focus and goals;
  - research problems, main research questions and hypotheses;
  - relevant areas to be consulted;
  - approach (type of research, main stages and methods);
  - expected (area of) contribution and deliverables;
  - time schedule.

The approach and methods used in this stage are described in Chapter 3.

2.6.2 Descriptive Study I (DS-I)

The DS-I stage aims at increasing our understanding of design and its Success Factors by investigating the phenomenon of design through reviewing the literature about empirical research, undertaking empirical research, and, in addition, through reasoning.[6] The starting point is the Initial Reference Model drawn up during RC and the preliminary Criteria.

Investigating the phenomenon of design has been a very rapidly growing research area in the past decade. However, the current status is far from satisfactory, as we discussed in Section 1.3. The large variety of influencing factors studied and the variety of aims not only emphasise the complexity and extent of design as a research area, but also reveals, as a consequence of the low number of studies that deal with the same topic and the small number of cases in each study, the limited understanding we still have of design.

Most important in view of our methodology, is the fact that few studies focus on the explicit link between success and the influencing factors investigated. The usual focus is on links between pairs of influencing factors, occasionally linking these together, but without attempting to combine all together into a network of influencing factors that can form the basis for a comprehensive model or a theory of design and for the development of effective design support. The availability of results related to success or failure is particularly important for the development of design support. For example, a finding such as '20% of designers do X, 40% do Y and the rest do Z' can be useful for developing support, in the sense that these types of behaviour have to be taken into account. However, it does not provide any information for *improving* the situation, *i.e.*, to determine what to support and what to discourage to affect success. The link between this finding and success is needed.

This problem is aggravated by the fact that many publications do not provide sufficient details of the research approach to be able to compare different studies and to determine whether the findings are a suitable basis for one's own research. Most publications describe how data was collected, but not always detailed enough to determine the circumstances under which the data was collected. Very few

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[6] Our use of the term 'descriptive study' is broader than its commonly used meaning in Social Sciences, and covers all types of study to investigate a particular phenomenon (for details see Section 4.1).

publications describe the data processing and analysis methods in sufficient detail to be able to verify the results. Moreover, the basic assumptions of the researchers that guided their interpretation of the data is not made explicit, and there is no evidence that the findings were validated. The analysis of Cantamessa (2001) of the 718 papers published in two major conferences on engineering design confirms our observations, showing that even basic information is lacking. He found that of the 111 papers describing empirical studies, 41% did not declare the sample size, 25% did not present the implications of the findings, 22% did not give the unit of analysis (the factor that was studied) and 10% did not state the research approach. As far as the research approach was described, he found little or no reflection on the methods and the approach that had been used.

We further noticed in many empirical studies inconsistencies between aim (criteria), research questions and hypotheses, data-collection method, data-analysis method, interpretations and conclusions. We found conclusions that cannot be drawn on the basis of the collected data, methods that are unsuitable to answer the research questions, *etc*. Moreover, findings, assumptions, interpretations and conclusions are often not clearly separated, thus providing a problematic or even unsound basis for further use.

There is often a tendency to use research methods that are most popular, rather than most suitable for the research goals and questions. A central reason for this is that many design researchers have an engineering background; in contrast to many other disciplines, research methods are usually not part of their curriculum. Where research training has been provided, this is likely to have covered quantitative methods for conducting natural science experiments. To investigate the phenomenon of design, a much wider variety of research methods, both qualitative and quantitative, from various disciplines has to be used to investigate the facets and aspects involved. Most design researchers will have heard of the more common of these methods, but are usually unaware of the underlying paradigms and lack knowledge about the pre-requisites for applying these methods.

In Chapter 4 on DS-I and in Appendix A, we attempt to address the above issues by providing a research approach, guidelines and methods, as well as summaries of existing methods from other disciplines, the main concepts to be familiar with, and pointers to the relevant literature. However, this information will never replace the importance of consulting experts in the relevant disciplines to ensure the most suitable methods are chosen and applied correctly.

The objectives of the DS-I stage are:

- to obtain a better understanding of the existing situation by identifying and clarifying in more detail the factors that influence the preliminary Criteria and the way in which these factors influence the Criteria;
- to complete the Reference Model including the Success Criteria and Measurable Success Criteria;
- to suggest the factors (possible Key Factors) that might be suitable to address in the PS stage, as these are likely to lead to an improvement of the existing situation;

- to provide a basis for the PS stage for the effective development of support that addresses those factors that have the strongest influence on success, and can be assessed against the Criteria;
- to provide detail that can be used to evaluate the effects of the developed support in the DS-II stage.

The deliverables of the DS-I stage are:

- a completed Reference Model, Success Criteria, Measurable Success Criteria and Key Factors, that:
  - describe the existing situation and highlight the problems;
  - show the relevance of the research topic;
  - clarify and illustrate the main line of argumentation; and
  - point at the factors that are most suitable to address in order to improve the situation;
- an updated Initial Impact Model;
- implications of the findings for the development of support and/or for the evaluation of existing support.

The approach and methods used in this stage are described in Chapter 4.

2.6.3 Prescriptive Study (PS)

Ultimately, design research is about developing support for improving design, even though this might not be the focus of an individual design project. The development of design support has a long tradition and is still a dominant research theme. However, there is little evidence of extensive use of valid empirical data: development relies on single findings, on assumptions and sometimes on experience. Many of the empirical results seem unknown to those developing support. Possibly because the research communities developed relatively independent of each other (see Section 1.3.1), and because many empirical studies do not establish links between influencing factors and success (see previous section).

We have also encountered the argument that it is not necessary to look into the existing situation in design, if the intention is to automate a particular task, rather than assisting the designer in executing this task, and if the support is not intended to mimic the human design process, but is to be based on another approach. In our view, it is always relevant to understand the existing situation, because this is the context in which the support has to be introduced and used, in order to address a particular problem or need.

Increasingly, we observe PhD projects starting with a small investigation of the current situation. Such investigations are important, but often unfortunately used as the only source. The following example shows how using all available understanding of the existing situation, rather than relying upon single findings, influences the potential success of the developed support. Several studies show that designers spend a large amount of time on collecting information, such as Beitz (1979) and Hales (1987). Based on this understanding, developing a computer tool to more easily access information seems to be a suitable solution. A more recent study, however, shows that although large amounts of information about past designs are available in digital form, personal contact is still the most frequently used source for information; the information designers need is often not contained in such databases (Marsh 1997). As a consequence of these findings, a more promising solution would be to develop a support that captures this information, rather than focusing only on supporting search. That this solution still might only solve part of the problem, is revealed by two other findings: in searching for solutions, successful designers restructure and summarise information (Fricke and Pahl 1991), and experts often rephrase the question when asked for information (Ahmed 2001). Capturing and storing information 'as given' is obviously insufficient. Another type of support has to be developed.

We see some evidence that the increasing number of empirical studies starts having an effect and expect that this will give new impulses to the development, improvement and implementation of support.

With regard to the support that is developed, we have observed that most publications do not reveal the view on design underlying the support, *i.e.*, the vision of the researcher about the desired situation and the role of the support. The assumptions upon which the support is based are often not made explicit or are presented as facts. The earlier mentioned analysis of publications on design research (Cantamessa 2001) showed that in 47% of the 331 papers on support, motivations are absent: only in 33% of papers were they defined precisely. Making the views and assumptions explicit is important, because these influence the development of the support and its likelihood of success.

We have further observed, that a considerable amount of time is spent on details of the support – in particular if this involves software development – rather than on its concept, although the core research contribution often lies in this concept. The aim of a research project is rarely to develop a commercially viable support. The aim, usually, is to define the envisaged support, the **Intended Support,** and realise this to such an extent that its core concept can be demonstrated and the effects evaluated. That is, the support that is actually realised, the **Actual Support**, might differ from the Intended Support. However, little help exists to develop demonstrators, prototypes or drafts that are sufficient to evaluate the concept.

Regarding the approach applied to develop the support, little is published and reflections on the approach are rare. Interestingly, much support aims at aiding a more systematic design process, but in developing the support (which is a design process in its own right) some of the basic principles of systematic product development, such as a thorough problem definition and the generation of variants, do not seem to have been followed. Support can take any form (guidelines, checklists, methods, equations, procedures, reorganisation proposals, *etc*., see also Footnote 3 (page 4), and medium (paper, software, models, workshops, *etc*.). The support can combine several forms and media, *e.g*., a checklist to collect 'the voice of the customer', a software programme to process this data, and guidelines on how to incorporate the results in a product. Unfortunately, few of these possibilities seem to be considered when developing support.

We believe that a more systematic way of developing design support in a research project can address the above issues, if this approach includes: the use of empirical data; the development of a model of the desired situation to reveal the underlying vision and assumptions; the distinction between the envisaged, Intended Support and the Actual Support developed for evaluation; and the use of the basic principles of systematic product development.

The objectives of the PS stage are:

- to use the understanding obtained in DS-I or DS-II to determine the most suitable factors to be addressed in PS (the Key Factors) in order to improve the existing situation;
- to develop an Impact Model, based on the Reference Model and the Initial Impact Model, describing the desired, improved situation that is expected as a consequence of addressing the selected Key Factors;
- to select the part of the Impact Model to address and to determine the related Success and Measurable Success Criteria;
- to develop the Intended Support, that addresses the Key Factors in a systematic way, and to realise this to such a level of detail that an evaluation of its effects can take place against the Measurable Success Criteria;
- to evaluate the Actual Support with respect to its in-built functionality, consistency, *etc*., – the **Support Evaluation** – in order to determine whether to proceed to DS-II to evaluate the effects of the support;
- to develop an **Outline Evaluation Plan** to be used as a starting point for the evaluation in DS-II.

The deliverables of the PS stage are:

- documentation of the Intended Support:
  - Intended Support Description: what it is and how it works;
  - Intended Introduction Plan: how to introduce, install, customise, use and maintain the support as well as organisational, technical, infrastructural pre-requisites;
  - Intended Impact Model;
- actual Support: workbook, checklist, software, *etc*.
- documentation of the Actual Support:
  - Actual Support Description;
  - Actual Introduction Plan;
  - Actual Impact Model;
- results of the Support Evaluation;
- Outline Evaluation Plan.

The approach and methods used in this stage are described in Chapter 5.

2.6.4 Descriptive Study II (DS-II)

The DS-II stage focuses on the evaluation of support. In many PhD dissertations we have found that the developed support is not really evaluated in a way that allows an assessment of its effects, although realising these effects is said to be the goal of the research project. In other words, what is evaluated is not in line with what is claimed.

In particular we have seen inappropriate generalisations, where ‘generic methods’ are developed based on the analysis of a specific problem and evaluated using the same problem. In many cases, statements are made about the use of the support, although the evaluation involved only the researcher. Moreover, the developed support is often evaluated using existing products or processes only, that is, products and processes that are already known. In order to see the effect of a support, it needs to be applied without knowing the outcome. Furthermore, design support is expected to be used, eventually, to address the needs and problems that triggered its development. The emphasis on *use* implies that the human factor and the actual introduction and maintenance of the support in the user environment have to be considered. Research projects rarely address these issues. Hence, most evaluations are unlikely to reveal the *real* issues of using the support for design.

Notwithstanding this criticism on current evaluation practice, these evaluations can be a useful starting point for a first identification of the major issues. However, a more detailed evaluation addressing the above issues is required if the evaluation results are to be used: to determine whether the goals have been achieved; to inform improvement of the support; to increase our understanding of design; and to suggest how introduction should take place.

One of the reasons for the observed situation is the lack of involvement of users and practice *throughout* design research projects: to understand the current situation, to inform support development, and to evaluate. Fortunately, more and more researchers do involve users. More persistent reasons we hear for the lack of detailed evaluation are: the lack of time and availability of users; the supposed impossibility of obtaining valid results using a small number of cases; and the limitations of the actual support. A detailed evaluation is indeed time consuming; finding users and settings to evaluate the support is often problematic and may indeed result in a very small number of cases; and we cannot expect the actual support to be complete – in many cases it is a prototype or demonstrator of the intended support with limited functionality, robustness and coverage. A detailed evaluation can therefore be very difficult, requiring careful thought. Even then, generalisation of the results may be limited. As a consequence, detailed evaluation of the developed support is often neglected, but without it we can say little about the success of the support, as one of the outcomes of research. In our view, this is one of the main reasons that much of the design support developed in academia is not taken up in practice (see Section 1.3.2), and often not even by other researchers.

Many ways exist in which design support can be evaluated, but creativity is required to set up a proper evaluation that fits the aims and constraints of the project, while at the same time provides enough confidence in the proposed support. This makes DS-II a challenging but not impossible task: when well thought out, it is possible to carry out empirical studies that provide useful evaluation data within the timeframe of a research project. For this, the evaluation should be kept in mind *in all stages* of the research project.

Unfortunately, little guidance exists for selecting suitable evaluation methods. The 1996 NSF Workshop on research opportunities in engineering design concluded that “methods for validating the results of research in design need to be developed. We need to have the means with which to determine the value added by a tool or method, its reliability, and its scalability to practical problems. Such tests are hard, but without them we are doing philosophy” (Shah and Hazelrigg 1996). Nothing much has changed since, but the issue of evaluation is increasingly being discussed in the design research community (Frey and Dym 2006; Seepersad *et al.* 2006). Looking into other areas and their ways of evaluating research results that are intended for practice, we found interesting approaches and guidance, which are addressed in Chapter 6.

Based on our observations, we consider it necessary to distinguish between two types of evaluation, in addition to the commonly applied Support Evaluation in PS. The first type of evaluation, the **Application Evaluation**, aims to identify whether the support can be used for the task for which it is intended and that is does address the factors that are directly influenced (the Key Factors) in the way they are supposed to be addressed, *i.e.*, the focus is on *usability* and *applicability*. Using our earlier example, we need to investigate whether users understand the support that has been developed, whether they can use it, and whether it indeed improves the quality of the problem definition. In terms of the Impact Model we need to investigate the effect of the support on the value of the Key Factor(s). In the example shown in Figure 2.8 this is the effect of the support on the ‘quality of problem definition’. Some research projects do address this type of evaluation.

However, whether a positive effect on the Key Factor(s) indeed contributes to success, *i.e.*, whether the support is useful is not certain. The second type of evaluation, the **Success Evaluation**, therefore aims to identify whether the support has the expected impact *i.e.*, whether the desired situation represented in the Impact Model has been realised, taking into account that unexpected side-effects may occur. The focus is on *usefulness*. Using our earlier example, (see Figure 2.8), we need to investigate whether the percentage of time spent on modifications and the number of modifications have been reduced, and, most importantly, whether this has reduced time-to-market, *i.e.*, we need to verify the links from the Key Factor to the Measurable Success Criteria.

To a certain extent, DS-II also validates the findings of DS-I: the understanding gained from evaluating the support enables the evaluation of the Impact Model, which in turn enables the evaluation of the Reference Model, as well as a reflection on the chosen Success and Measurable Success Criteria. In that sense, DS-II also contributes to our understanding of success and the definition of metrics of success.

Evaluation is an essential part of development of support, and could therefore have been included as an activity in the PS stage. However, the decision to separate development from evaluation was taken deliberately to highlight the importance of formal evaluation of support and to make explicit the difference between the approach and methods required.

The approach and methods used in DS-II are similar to those in DS-I, but the aims are different: the aim of DS-I is to understand design, the aim of DS-II is to understand the impact of a support.

The objectives of the DS-II stage are:

- to identify whether the support can be used for the task for which it is intended and has the expected effect on the Key Factors (Application Evaluation);
- to identify whether the support indeed contributes to success (Success Evaluation), *i.e.*, whether the expected impact, as represented in the Impact Model, has been realised;
- to identify necessary improvements to the concept, elaboration, realisation, introduction and context of the support;
- to evaluate the assumptions behind the current situation represented in the Reference Model, and the desired situation represented in the Impact Model.

The deliverables of the DS-II stage are:

- results of the Application Evaluation;
- results of the Success Evaluation;
- implications and suggestions for improvement for:
  - the Actual Support;
  - the Intended Support, its concept, elaboration and underlying assumptions;
  - the Actual and Intended Introduction Plan including introduction, installation, customisation, use and maintenance issues;
  - the Actual and Intended Impact Model;
  - the Reference Model;
  - the criteria used.

The approach and methods used in this stage are described in Chapter 6.

2.6.5 Summary

Figure 2.1 can now be extended to include the deliverables of each stage. The result is shown in Figure 2.9.

2.7 Comparison with Other Methodologies

Few publications exist on DRM, although the need for addressing the methodological issues has been discussed for some time, *e.g.*, in Antonsson (1987); Duffy and Andreasen (1995); Eckert *et al.* (2003); Reich (1994a); Reich (1994b); Reich (1995), and our own publications. Some proposals for a methodology have been made in the area of engineering design, notably Bracewell and Shea (2001; Duffy and Andreasen (1995); Eckert *et al.* (2003); Langdon *et al.* (2001); Stacey *et al.* (2002). Researchers in the more artistic design areas, such as industrial design, graphic design and sculpture, are involved in a large interesting debate about design as research, see, *e.g.*, Buchanan (2004); Dilnot (2004); Galle (2002); Love (2002) but no methodology has been proposed.

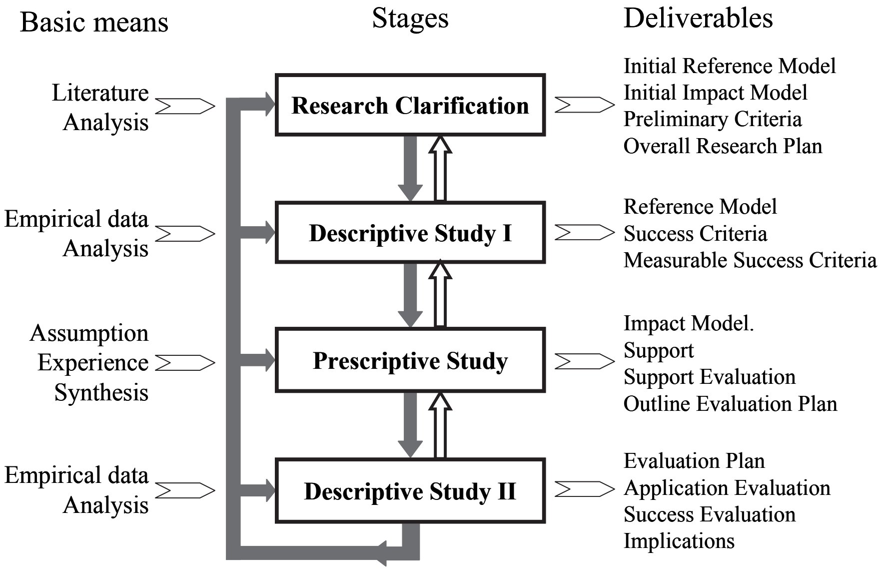

Figure 2.9 DRM framework: stages, basic means and deliverables

Two methodologies that are close to DRM are discussed below: the research framework and methodology of Duffy, Andreasen and O'Donnell, and the Soft Systems Methodology of Checkland.

The research framework developed by Duffy, Andreasen and O'Donnell (Duffy and Andreasen 1995; Duffy and O'Donnell 1999) stresses the need "to facilitate the research and development of appropriate means to support design […] and its management based upon a fundamental understanding of design." They develop the framework for conducting design research shown in Figure 2.10 "based upon the hypothesis that any developed tools (be they human or computationally based) will make an impact upon the design process itself when employed". Similar to DRM, they introduce criteria for evaluation based on reality and models: "The reality and models would act as the criteria upon which to base critical and objective evaluations of the consequent models, but when employed as tools would affect the 'reality' in which design is carried out" (Duffy and O'Donnell 1999). Because of the latter, they too distinguish between descriptive and prescriptive models: the former based on reality (our Reference Model) and the latter on "the envisaged or foreseen reality that would be considered as enhancing design practice" (our Impact Model). In contrast to DRM, their framework is characterised by three models: a phenomena model, a knowledge model and a computer model. This difference is in line with the focus of their framework: the development of computer support.

The general research methodology related to the framework consists of six steps: Design problem; Hypothesis; Research problem; Solution; Formal evaluation; and Documentation. The literature informs the first four steps; design practice informs the first and fifth step. Unfortunately, no details about the framework and methodology are available.

The methodology of Duffy and Andreasen shows overlap with the three-level model of evaluation described by Smithers in Donaldson (1991): (1) knowledge level: tests models and theories of the design process; (2) symbol level: tests the capability of knowledge representation and of control knowledge and its application; and (3) system engineering level: tests the implementation. Level 1 is similar to the validation of the Reference Model in DS-I in DRM; level 2 to the Support Evaluation in PS and part of the Application Evaluation in DS-II; level 3 relates to the evaluations in DS-II, although the distinction between Application and Success Evaluation is not made.

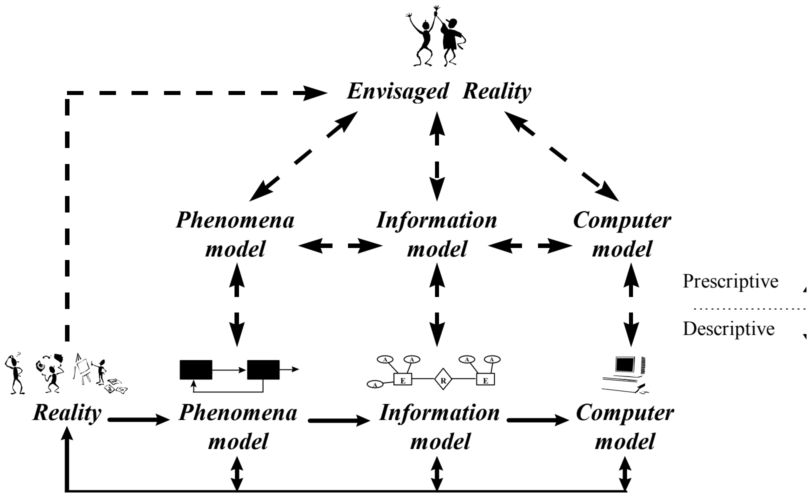

Figure 2.10 The DRM proposed by Duffy and Andreasen (1995)

The Soft Systems Methodology (SSM) of Checkland (1981; 1999) is the result of an Action Research programme, with the aim "to find ways of understanding and coping with the perplexing difficulties of taking action, both individually and in groups, to 'improve' the situations which day-to-day continuously creates and continually changes" (Checkland 1999). Action Research is an approach for introducing and evaluating change, originally in organisations and programmes, but increasingly within design research (see Appendix A.4.9 for more details). SSM is "concerned with problem situations, not with problems, in which there are felt to be unstructured problems" (Checkland 1981) and "explores the value of the […] ideas captured in the notion of 'system'" (Checkland 1999) to find solutions that are "feasible and desirable" (Checkland 1981).

The main stages of SSM show a strong similarity with DRM. First, reality is analysed and a description of the essence created. Based on this, a description of the ideal situation is created, which is compared with reality to generate proposals for improvement of reality. The proposals are introduced and the 'new' reality is analysed. This cycle is repeated until the results are satisfactory. The result of each cycle is not only an improvement of reality, but also a better understanding of reality and of the quality and effects of the proposed actions.

In contrast to DRM, the main focus of SSM, and other action research approaches, is on on-site evaluation of the newly developed support, which is prone to result in local solutions and gradual improvement using short-cycles between support generation and evaluation. SSM is very much embedded in practice, which is also its advantage. In DRM, the aim is to generate more generic solutions, evaluating the initial support in a realistic, but not necessarily the real situation, and to do these using fewer but longer cycles. One reason for the differences is the types of solutions for which the methodologies were initially developed. Organisational changes and welfare programmes, the original areas of action research, are more localised and cannot be evaluated off-site, in contrast to most of the design support on which DRM focuses. An overlap, however, exists and many of the methods described in SSM can be usefully applied as part of DRM.

2.8 Main Points

The main points of this chapter can be summarised as follows.

- This chapter presents the outline of our methodology for design research DRM and an overview of its stages and main concepts.
- The specific objectives of DRM are to provide: a framework for design research, help to identify research areas and develop the argumentation; guidelines for research planning; guidelines for rigorous research; help to select research methods; a context for positioning research projects and programmes; and, encouragement to reflect on the approach.
- While using DRM one must be flexible and opportunistic, pursuing promising, unexpected avenues that may lead to new solutions.
- The main stages of DRM are: Research Clarification (RC), DS-I, PS and DS-II.
- RC helps clarify the current understanding and the overall research aim, develop a research plan and provide a focus for the subsequent stages. The deliverables are: an Initial Reference Model, an Initial Impact Model, a preliminary set of Criteria, and an Overall Research Plan.
- DS-I aims at increasing the understanding of design and the factors that influence its success by investigating the phenomenon of design, to inform the development of support. The deliverables are: a Reference Model, an updated Impact Model, Success and Measurable Success Criteria, as well as implications of the findings for the development of support.
- PS aims at developing support in a systematic way, taking into account the results of DS-I, developing an Impact Model, developing support (distinguishing between Intended and Actual Support), and undertaking continuous Support Evaluation. The deliverables are: an Impact Model, descriptions of the Intended and Actual Support, the Actual Support, Support Evaluation results, and an Outline Evaluation Plan.
- DS-II focuses on evaluating the usability and applicability of the Actual Support (Application Evaluation) and its usefulness (Success Evaluation). The deliverables are: Application and Success Evaluation results and suggestion for improvement of the Actual and Intended Supports, as well as the Reference and Impact Models.
- Both DS-I and DS-II aim at developing an understanding of the phenomenon of design. While DS-I aims to understand design ‘as-is’, DS-II

aims to understand the impact of a support. DS-II involves intervention into the process – the introduction of the support.

- Based on the depth in which individual stages are executed, seven different types of design research are distinguished.
- DRM is not a set of stages and supporting methods to be executed rigidly and linearly. Multiple iterations within each stage and between stages are possible, as well as parallel execution of stages.
- A project can start in any of the stages of DRM, but the links to the other stages should be addressed, even if these are not executed within the project: research should both build upon existing and contribute to future research.
- In DRM, descriptions of the existing and the desired situation are modelled as networks of influencing factors. Factors are aspects of the situation under consideration that influence other aspects of this situation.
- The Reference Model represents the existing situation in design and acts as a reference for benchmarking intended improvements.
- The Impact Model represents the desired situation, and shows the envisaged impact of the support. The models develop as understanding grows.
- In most instances, the Impact Model cannot be derived directly from the Reference Model. The introduction of assumptions is necessary to represent the desired situation.
- An influencing factor is represented as an attribute of an element for which an operational definition can be formulated. Key Factors are those influencing factors addressed directly by the support. The links between factors represent how the factors (are desired to) influence each other.
- Criteria are the desired values of the factors a research project sets out to understand and/or influence, as described in the research goal. Criteria can be relative or absolute, qualitative or quantitative. These are used to judge the outcome of the research against the goals.
- Success Criteria relate to the ultimate goal to which the research project or programme intends to contribute.
- When Success Criteria cannot be used to judge the outcome of the research, given the resources available in the project, Measurable Success Criteria are selected that can serve as reliable indicators of the Success Criteria. The term measurable refers to the possibility to measure the criteria within the project.
- The support can take any form (guidelines, methods, equations, reorganisation proposals, *etc.*) and medium (paper, software, models, workshops, *etc.*).
- The Actual Support is a prototype or demonstrator of the Intended Support with limited functionality, coverage, and performance, but sufficiently developed to enable the evaluation of the core contribution of the researcher.
- Evaluation should be kept in mind in all research stages.

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