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STRUCTURING THE PROCESS OF DESIGN RESEARCH - A NECESSARY STEP TOWARDS ENSURING SCIENTIFIC RIGOR

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ABSTRACT
Almost every researcher is aware of less successful or even failed Ph.D. research projects or contracted industrial research projects. In most of these cases, there are methodological, structural and procedural reasons in the background. In this paper I argue that research projects need to be decomposed into procedural units and these procedural units should be complete from a methodological as well as from an epistemological point of view. The concept of research cycle has been considered as a practical manifestation of these procedural units. A research cycle comprises a part in which intelligence for generating a new theory is attained and a part in which the new theory is scrutinized by applying critical thinking. These parts can be transformed into a sequence of stages, having their own objectives. The activity elements of these stages are explained in the paper. The proposed approach enhances objectivity, reproducibility, rational scrutiny, empirical testability, reliability of theories, as well as justification and validity. The benefits of applying this approach have been observed in more than ten Ph.D. research projects and twenty graduation projects so far.

Keywords: systematic design research, procedural structuring, methodological framing, research in design context, design inclusive research, operative design research, research cycles, research methods

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1 INTRODUCTION

In the overwhelming majority of published design research articles and papers, accounts of success stories and positive results are given. Yet, almost every researcher is aware of Ph.D. research projects that have been finished with a struggle or even failed, contracted industrial research projects that were not completed on time or with the expected results, academic portfolio research programs that suffered from a poor management and conduct, or collaborative research projects that achieved a sub-optimal knowledge synthesis only. In most of the cases, the reasons can be traced back to lack of proper procedural insights, poor process dissecting or structuring, or improvised execution of activities. The other side of the coin is that the total number of articles and papers on logical structuring of research processes and on procedural support of research undertakings seems to be much less than that of the studies addressing epistemological issues, methodological principles, and/or operative research methods. In the shadow of the debates and speculations about the ontological and epistemological status of design research and the intentional and methodological differences implied by various conceptual frameworks, the procedural issues of planning research programs and projects are receiving less attention than needed, and are often treated with insufficient depth. This negligence may cause hazards in the case of complex, multi-year design research projects, such as Ph.D. studies.

The sketched situation indicates the need for further research in procedural aspects of research methodologies and practical research conducts. The necessity of advancement in this direction was also emphasized by other design researchers [12]. To achieve a higher level of rigor, design researchers need to apply both *procedural structuring* and *methodological framing* in research projects [8]. Procedural structuring means dissecting complex research projects into better manageable logical units. In addition to putting the research inquiry into design contexts, methodological framing facilitates a systematic approach and a proper combination of design (creative and integrative) and research (analytic and reductive) activities [3]. However, proper procedural structuring and methodological framing of design research is not a simple case in practice. Typically, design processes (i.e. conceptual formation and evolving virtual/physical materialization of artifacts) are regarded as the primary process of knowledge inquiry in design research [10]. Knowledge is extracted and synthesized by means of many different intellectual activities, which are variously called *critical design practice*, *design discourse*, *design study*, *design experiments*, *narrative design reviews*, *design action research*, *design automation*, *research through design*, *exploration by design practice*, or *pragmatic design philosophy*, to name but a few [11]. They all are depicted as designerly ways of knowledge exploration [1]. Though there is no doubt about their usefulness in aggregating practical research knowledge that may even be decontextualized, most of them do not support disciplinary inquiry and foundational design knowledge. Nevertheless, these forms of knowledge inquiry do intrinsically not strive after scientific rigor. As a matter of fact, we still lack a clear-cut definition of the criteria of when a designerly inquiry can be regarded as scientific research, since there are at least as many opponents as advocates of imposing the standard criteria of scientific rigor and quality measures [16]. Nevertheless, in this paper, I try to concentrate on doing disciplinary design research that respects the principles of scientific rigor, while also targets advancement of design practices.

In the past years the motivation for my research was the realization that complex, multi-year design research projects cannot be conducted in an intuitive or ad-hoc manner when optimal results are targeted. Therefore, I was striving after a straightforward procedural structuring and methodological framing approach. Primarily, *middle-range design research projects*, such as PhD research, multi-year post-doctoral research, and externally funded medium term research projects, were aimed at. Actually, the specific objectives were: (i) to find the principles of achieving a harmony (rational balance) between the contents (scope and extent) and the process of completing a research project, (ii) to develop theoretical concepts and practical constructs for procedural structuring of design research projects, (iii) to specify a generic, but pragmatic process flow model that covers explorative, constructive and confirmative phases of knowledge inquiry, and (iv) to define the sequence of research actions and a choice of research methods that can be applied in contextualized design research processes in various stages of progression. The next section of the paper sets the stage for further discussion by introducing a reasoning model that interconnects the organizational and methodological aspects of design research. Starting out of the fact that a research procedure is driven by various activity constructs that define and operationalize it, the third section elaborates on the notion of research cycle as a *fundamental procedural unit* of research projects and the possible methodological framing, while the fourth section explains the stages of logical progression within various research cycles. The fifth section deals with some major criteria for scientific rigor and discusses the contribution of the proposed procedural structuring and methodological framing to its manifestation.

2 SYSTEMATIZING THE CONDUCT OF DESIGN RESEARCH PROJECTS: A REASONING MODEL

In order to clarify the procedural aspects of design research processes, let us consider and interpret the reasoning model shown in Figure 1. Design research is typically conducted in the framework of a *research program* or of a *research project* [5]. Research programs are organized activities of governments, organizations and institutions to eliminate large-scale knowledge gaps by addressing a bunch of hot research objectives. Design research programs are distinguished as foundational (disciplinary) or operative (practical), and as mono-disciplinary, inter-disciplinary, multi-disciplinary, and/or trans-disciplinary. Foundational design research programs, such as portfolio research programs or strategic alliance research programs of knowledge institutions are organized for advancement of disciplinary knowledge and tend to focus on fundamental or abstract phenomena. On the other end, the objectives of operative research programs come from some concrete practical needs and new knowledge is typically generated by critical and systematic reflections in processes that are usually iterative and blended with original know-how, technology, or prototype development.

When executed, research programs are decomposed into a set of interrelated research projects, which can be conducted by a team of researchers or individual researchers with defined objectives, resources, capacities, activity scenarios, and time frames. It is becoming gradually accepted that research projects should be conceptualized and conducted as *structured processes* (systematic activity flows) including specific end-objectives and intermediate objectives, and knowledge availing milestones as recognizable decision points. Towards this end, research projects need to be decomposed into procedural units. I consider *research cycles* as a practical manifestation of these procedural units (Figure 1). A research cycle is a systematic inquiry process with a specific research objective and strategy. It is assumed that these procedural units are *complete* from a methodological as well as from an epistemological point of view. Completeness supports proper justification of true beliefs. While research programs and research projects play primarily organizational role in doing design research, research cycles represent a kind of transition from the organizational side to the methodological side of design research. In other words, a research cycle has a dual nature so as to serve as a bridge between the organizational management and methodological specification of research activities.

Nonetheless, research cycles as logical units are also of epistemological and practical importance. A research cycle is an activity period in which (i) data, information and knowledge are aggregated, (ii) used as a basis of new assumptions and actions, and (iii) new findings are generated, tested and consolidated. Hence, a research cycle can be seen as a structured flow of research activities. It includes logical groups of research activities, which are jointly referred to as *research motion*. This term has been chosen to express progression toward the defined objectives including a set of meaningful formal proposals. A research motion is all the activities which are made, for instance, in order to aggregate secondary data, derive a theory from related hypotheses, or validate findings outside the context they have been discovered. A research motion includes a set of related *research actions*, for instance, for a qualitative or a quantitative study of literature, or statistical evaluation of research data, or sampling subjects for an interrogative inquiry. Thus, a research action is an organized effort (causation of

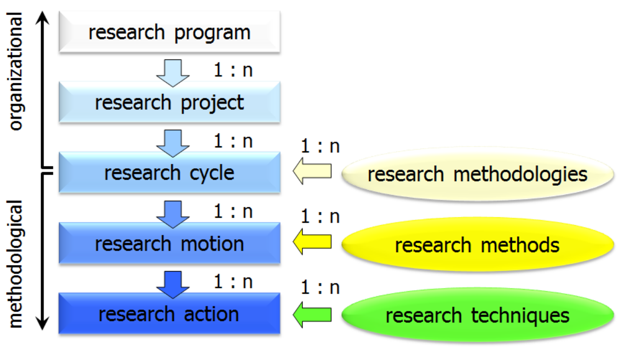

Figure 1 A reasoning model for systematizing the conduct of design research projects

change) to accomplish a specific focused objective.

The three procedural constructs introduced above have direct implications from a methodological perspective. Their operationalization needs proper methodological constructs. Namely, a research cycle needs to be methodologically formalized by using a relevant framing methodology, and enabled by a given instantiation of a working methodology. Methodological framing is an important reasoning step that precedes the actual problem solving and guides its systematic execution [6]. A *framing methodology* can be seen as a meta-methodology, which advises design researchers on how to conceptualize and structure a research cycle from a methodological (procedural) point of view, and on what concrete methodologies to consider at solving the knowledge inquiry problem at hand. Simply put, a framing methodology offers a reasoning model for determining the research process and approach. A *working methodology* is an intellectual construct that specify the manner of arriving at a solution and advises on the appropriateness of some methods, the principles of orderly combinations, and the systematic practices of application in the given context. It is a fallacy to imagine that research in a research cycle can be anything else than a multi-method research.

Design research imports many research methods from its background sciences and other related sciences, but it also develops its own research methods. Therefore, the range of existing design research methods is extremely wide. The two fundamentals categories are standard (domain independent) and specific (domain/task dependent) methods. In addition, the objective (fact/theory generation or fact/theory testing), the nature (qualitative or quantitative), and the dualities (e.g. empirical-rational, or unbiased-participatory) are also often considered as secondary classification principles. *Standard methods* are sorted as: (i) aggregative (e.g. literature study, document analysis, query-based web search, information mining), (ii) observational (e.g. naturalistic observation, laboratory observation, protocol study, instrumented observation), (iii) interrogative (e.g. questionnaire survey, in depth interview, self-reporting, focus group session), (iv) experimental (e.g. true experiment, quasi-experiment, instrumented measurement, sample analysis), (v) interventional (e.g. active diagnosis, physical testing, clinical testing, user trial), and (vi) operative (e.g. mathematical modeling-based analysis, computational model investigation, computer simulation-based study, comparative case study).

To be termed scientific, a method of inquiry must deal with justifiable rational thoughts or observable and measurable empirical evidence subject to specific principles of reasoning. A research method is a composition of *research techniques*, so as a research motion is a composition of research actions. Though many other classifications are possible and used, I have sorted research techniques into the following categories: (i) conduit techniques, (ii) sampling techniques, (iii) interrogation techniques, (iv) data coding techniques, (v) rating techniques, (vi) weighting techniques, (vii) error reduction techniques, (viii) measuring techniques, (ix) descriptive statistical techniques, (x) predictive statistical techniques, (xi) meta-analysis techniques, (xii) and consolidation techniques. They operate on the data, information and knowledge as (i) pre-processing, (ii) in-processing, (iii) post-processing, or (iv) cross-processing techniques. The range of specific research techniques is so wide and dynamically changing that a classification can be anything but complete.

3 TOWARDS PROCEDURAL STRUCTURING OF DESIGN RESEARCH PROJECTS

Procedural structuring is preceded by organizational and orientation matters. As shown in Figure 2, research projects typically entail three phases, namely: (i) a preparation, (ii) an execution and (iii) a valorization phase. The *preparation phase* not only creates a platform, but also gives orientation to the whole of a research project. There are five aspects that are to be considered in the preparation phase of every research project: (i) the target professional domain, the possible focus and scope, and reasonable objectives of research, (ii) the current state of knowing, dominant trends, significant competitors, possible cooperation partners in research in the concerned domain, (iii) resources available for the research project (human capacities, research infrastructure, investment grants, expertise, and time frame), (iv) time estimation and scheduling of the research motions and actions, and development of a comprehensive execution plan, and (v) a forerunning impact analysis of the expectable results.

The whole of the research project seems to be a *black box* at the very beginning of planning. It becomes a *white box* only after finishing the process of inquiry (i.e. when all actions are done and results are known). The abovementioned preparatory actions can however be not completed without considering the specific details of conducting the research. This is the *main challenge* of research

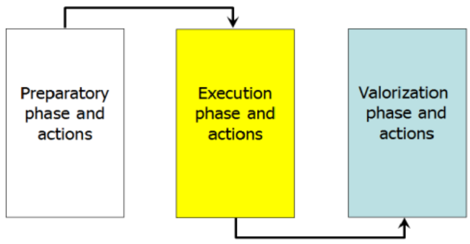

Figure 2 Three main phases of conducting scientific research projects

project development. The lack of specific information implies speculative assumptions, reasoning based on past experiences, and estimation of quantifiable characteristics of the planned project. This guesswork can be made more reliable if a complex project is decomposed into meaningful logical units that shed light on the actions and methods that are required to achieve the research objectives. Thinking of research cycles at this early phase of project management has been found useful. It allows harmonizing the scope of research and the execution procedure. It also supports the work-package oriented thinking and decomposition that is typical, for instance, in EU founded research programs.

In the planning phase, research projects are seen as possible scenarios of multiple research cycles, which will turn into a workflow of research motions in the execution phase. Execution of a simple project may happen in one single research cycle, while research projects of non-trivial complexity should be dissected into *successive research cycles*, the number of which is determined by the overall complexity of the project and the specific research objectives. As a rule, each specific research problem, generic research question, working hypothesis, and research design calls for its own research cycle in order to be treaded systematically and effectively. In this context, a research cycle is an occurrence of a sub-process, which is repeated in adapted forms as the research process advances towards the set objectives. As discussed in the next section, a research cycle maps the elements of a set of research motions (including their investigation and decision proposal) to a series of procedural stages depending on the considered methodological framing. In the language of mathematics, the set of procedural stages can be called the *orbit of the cycle*.

A non-dispensable part of research projects is the *valorization phase*. In this phase the project as a whole can be reflected upon and actions are made for dissemination and exploitation of the results. This includes: (i) assessment of the conduct of the project and potential utilizations of the results, (ii) academic and industrial dissemination of the results, (iii) business and utilization plan development, and (iv) exploration of future research opportunities. It has to be noted that, in particular in case of large-scale multi-year projects, the preparatory phase and the valorization phase may to some extent overlap with the execution phase. This most often happens due to incompleteness of information and superficiality of estimations in the preparatory phase, or to the emergent uncertainties of the process. These are seen however as pragmatic issues that do not have influence on the above demarcation of the three main phases of research projects.

In the definition of research cycles the ultimate objective of the project also plays an important role. Between the point of departure in knowing and the set objective of knowing many intermittent milestones can typically be identified. These milestones of knowing can be considered as *objectives* of the subsequent research cycles. Before defining the content and the design of the research cycles these specific objectives should be defined. It is an indication of the correct decomposition of a research project into research cycles if they make it possible to achieve the set objectives and altogether add up in an evolving path of knowing leading to the ultimate objectives of the project. The goal of procedural structuring is to *reduce the need for adaptation* of the ultimate objective of the research project or the intermediate objectives of the research cycles, and this way the unnecessary procedural iterations.

4 STAGES OF PROGRESSION WITHIN VARIOUS RESEARCH CYCLES

I assume that a research cycle is, by definition, an epistemologically and methodologically complete procedural unit of scientific inquiry. A research cycle is deemed to be *epistemologically complete* if not only exploration of new knowledge has been done, but the new knowledge (the facts and their relationships) has been logically and/or empirically properly tested, justified and validated. *Methodological completeness* means that the research methods and techniques have been chosen properly, all research motions and actions have been completed properly (i.e. using a correct and unbiased mixed methods approach), the research methods and techniques have been validated, and all

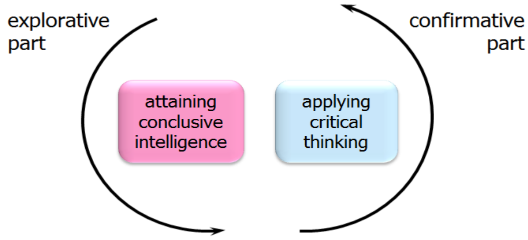

Figure 3 Kernel of a research cycle

influential factors have been investigated in order to achieve the above epistemic characteristics. It follows from the above assumptions that a research cycle should comprise a part in which intelligence for generating a new theory is attained and a part in which the new theory is scrutinized by applying critical thinking. The part focusing on data generation and theory development is called *explorative part*, and the part focusing on theory justification and validation is called *confirmative part*. As shown in Figure 3, there is a transitive relation between the exploration part and the confirmation part. The connector is the *new theory* which is the output of the exploration part and the input of the confirmation part. Here two comments must be made. First, concerning epistemological and methodological completeness, we have to pay attention to the various different *science philosophical platforms* and viewpoints that may affect the interpretation of completeness, and accept all epistemological and methodological limitations that have in the past been explored by science philosophers. Second, it is not dictated by any reason that epistemological and methodological completeness should be achieved within one particular research cycle. It can be achieved over two, or even more research cycles, which then however need to be designed and managed as (epistemologically and methodologically) *connected cycles* of the research project.
Based on the investigation of previous proposals for quantitative and qualitative research conducts and the study of past engineering and design research projects, the kernel shown in Figure 3 has been transformed into a *sequence of stages*. Every stage has its own objective and has been named accordingly: (i) knowledge aggregation, (ii) research assumptions, (iii) theory development, (iv) logical justification, (v) validation of conduct and findings, and (vi) consolidation of knowledge (Figure 4). In my interpretation, this structuring can be applied to cycles of foundational (disciplinary) and pragmatic (operative) research projects equally well. Both empirically-based and rationality-driven research processes in natural, human and social science reflect the same pattern. It is also easy to show that it can also be applied to formalization in operative research projects. As discussed by Susman and Evered, a typical *action research cycle* is formed by five stages: (ii) diagnosing, (iii) action planning, (iv) action taking, (v) evaluating results, and (vi) specifying learning [15]. Extending this with (i) aggregation of knowledge, which is of paramount importance even in case of idiosyncratic research, the above action research cycle shows a very strong similarity with the above described pattern of stages. This can be explained by the fact that operative design research, like action research, typically introduces a change in various forms and by various means. The carrier of the change can be evolving product prototypes, design methodological frameworks, new process flows, bodies of design knowledge, novel design tools, or innovative system architectures. Diagnosing is, among others, concerned with the identification and definition of a problem to be solved (making assumptions).

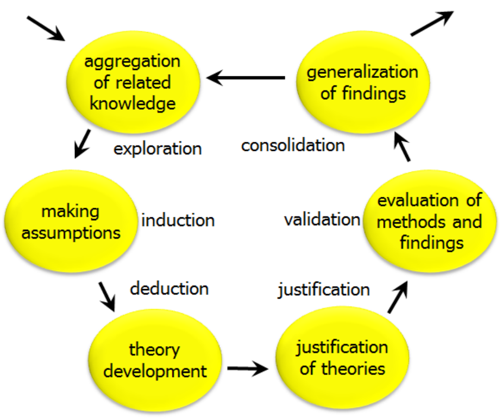

Figure 4 Stages of progression within a research cycle

Action planning considers alternative courses of action to solve the problem (theorizing). Action taking includes the selection and realization of one course of action (justification of feasibility). Evaluating comprises the study of the outcomes of the selected course of action (validation of results). Specifying learning is the stage in which the study accomplished in the previous phases will be structured in the form of general findings (generalization).

The *first stage* of a research cycle concentrates on gathering relevant knowledge both from secondary sources (e.g. literature, Internet, documents, etc.) and from primary sources (e.g. observations, experiments, interrogations, etc.). This *knowledge aggregation* is much more focused than the orientating knowledge collection in the preparatory phase because it is governed by the specific objective of the research cycle. The focus and scope of knowledge aggregation are governed by a *reasoning model*, which not only hints at the sources of knowledge, but also indicates the research motions and actions needed. In addition to compiling knowledge, the goals of the explorative activities are: (i) ordering the obtained knowledge according to the reasoning model, (ii) formulation of a critique of the current understanding and existing approaches, (iii) identification of the limits and knowledge gaps of current knowing and opportunities for progression (research actions), (iv) defining the research strategy and the needed refinement of the research objective for the rest of the research cycle. Multiple methods, both qualitative and quantitative, working towards primary data and working with secondary data, are used for knowledge aggregation in a complementary fashion. This stage can be considered completed when sufficient information is available for making assumptions for the rest of the research cycle.

The *second stage* is for making research assumptions based on the specific findings of the first stage. Inductive reasoning, taxonomic categorizations, and conceptual abstractions are applied as reasoning techniques to arrive at sufficiently *generic assumptions*. Generalization is needed because design research is interested in knowledge problems of widespread interest (that is, in the general rather than in the individual, though it does not exclude investigation of idiosyncratic cases). The most important research assumptions are: (i) phenomena to be studied, (ii) specific research objective(s), (iii) contexts of knowledge problem, (iv) working research questions, (v) working research hypotheses, (vi) overall research design, (vii) research concepts, (viii) research constructs, (ix) specific and accompanying research variables, (x) research methods and techniques, and (xi) aspects of justification and validation. These are different for every research cycle. Though the above order might seem to indicate a sequence of execution, the research assumptions should be considered and *made concurrently* to be consistent and harmonic. This stage of making assumptions is linked to the stage of theorizing through the working hypotheses. Because of this bridge function, appropriateness, testability and strength of theorizing of the working hypotheses are true concerns in the presented procedural approach.

In the *third stage* of a research cycle various empirical and/or rational motions are made to develop a theory which is able to fill in the knowledge gap at hand (that is, to describe, explain, predict or control the studied phenomena in design context) [4]. The objective is to arrive at an *abstract scientific theory* that is potentially open to disconfirmation by evidence. As a basis of theory development, it is presumed that all generalizing assumptions made in stage two are defendable and the claims of the working hypotheses are true. Theory forming may be done either by *deductive theorizing* (adaptation of more generic theories), or by *inductive theorizing* (composition of implications of hypotheses). The concrete goals of the latter are two-fold: (i) to provide evidence that the working hypotheses are true, and (ii) to explore the implications of the hypotheses and combine them into the body of the theory sought for. The *research strategy* is supposed to be able to inform on how to get to a sufficiently comprehensible and dependable theory from the research hypothesis through a validatable process of theorizing [14]. The derived theory may (i) provide an initial circumscription of a discovered new phenomenon (exploratory theory), (ii) attain a detailed and comprehensive account (descriptive theory), (iii) identify the interrelationships of input and output research variables and establish reasons (explanatory theory), (vi) forecast future outcomes (predictive theory), and (v) specify and evaluate possible interventions and feasible changes (controlling theory). The theories are composed of generalizations which are not tied and relevant only to particular cases. Thus they support understanding, but can also be used for enhancement in multiple contexts, among other things for building design prototypes that serve downstream confirmative stages as *research means*.

The *fourth stage* is dedicated to a logical and conceptual justification of the proposed theory. Justification determines if a design theory suffers from a fallacy. Theories may be discarded for not being logically consistent (if one contradicts itself) or for failing to correspond to the observable reality in some non-trivial way. There are various modes of inference as *means of justification*. In case of design research, justification much more often happens indirectly, than directly. Direct justification can be based on rational (e.g. mathematical) means, or on empirical (e.g. observational, or experimental) means. Both suffer from the induction problem that is accompanying finding confirming or disproving cases. This has been investigated by many science philosophers in the context of both *verification and falsification*. In addition to testing the level and the limits of logical truth of the derived theory, also its conceptual integrity (consistence) and implications need to be taken into consideration. Indirect justification is governed by the strategy of '*reasoning with consequences*'. The logical basis of this empirically oriented family of approaches is syllogism that claims that true conclusions can only be derived from true assumptions (that is, if the consequences can be justified, the theory that implied those consequences must be true). In practice, the reasoning with consequences approach involves *operationalization of the proposed theory* by creating some sort of design prototypes. Obviously, theories can rarely be tested as a totality, but from particular aspects only.

In the *fifth stage*, validation of the derived facts, laws and theories, and their implications takes place. Validity refers to the extent a study can be regarded as accurate and reliable, and its findings relevant and useful in a given context, or in general. On the whole, *validity* expresses the extent to which an actual research project or cycle satisfies the objectives that it was intended to achieve. Depending on the time of completion, validation can be: (i) prospective, (ii) concurrent, or (iii) retrospective validation. Based on the periodicity of application it can be: (i) one-time validation, (ii) revalidation after change, and (iii) periodic revalidation. According to its aspect, validation can be internal or external validation. *Internal validity* is the extent to which the research design and the conduct of a study are likely to have prevented systematic bias and therefore the results may be considered reliable. Major aspects of testing internal validity in design research are: (i) investigator validity, (ii) concept validity, (iii) construct validity, (iv) method validity, (v) instrument validity, (vi) face validity, and (viii) environment validity. *External validity* concerns the extent to which the (internally valid) results of a study can be held to be true for other cases, for example to different people, places or times [2]. In other words, it is about whether findings can be validly generalized. Hence, the measure of external validity expresses transferability or generalizability of the findings from one study to other populations, settings and arrangements. However, it is rather difficult, if not impossible, to capture the real meaning and manifestation of external validity with one single characteristic or feature in design research. There are four major aspects of external validity: (i) sampling validity (if research participants are true representatives of the general population and how well the sample used can be extrapolated to a population as a whole along relevant dimensions), (ii) ecological validity (measuring the extent to which research results can be applied to real life situations outside of research settings), (iii) utility validity (interpreting or measuring how much the new theory, model or prototype is useful for the design practice in a broader sense), and (iv) similarity validity (consideration of the comparability of the conducted research project and other similar research projects). According to my view, we can talk about *general validity* if, and only if, rigorousness, soundness, cogency and convincingness are reflected by the research design and findings.

Finally, in the *sixth stage*, consolidation of the new knowledge (proposed theory, laws and facts) is in the focus. As a forerunning step, the investigation of external validity already addresses issues related to generalizability and reusability and provides information for consolidation. It informs about how strongly the conducted research is dedicated to the given research problem, and what may be expected to occur in other research contexts. *Consolidation* can be seen from the perspective of the conducted research project (i.e. of the follow-up research cycles), and in more general disciplinary contexts.

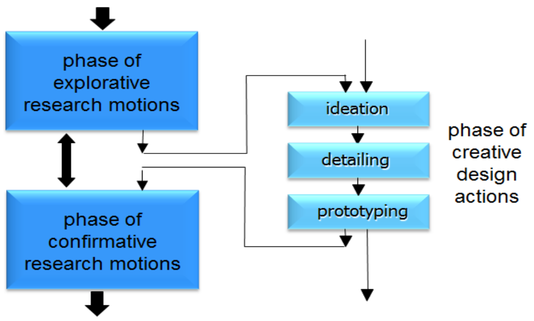

Figure 5 Stages of progression within a DIR cycle

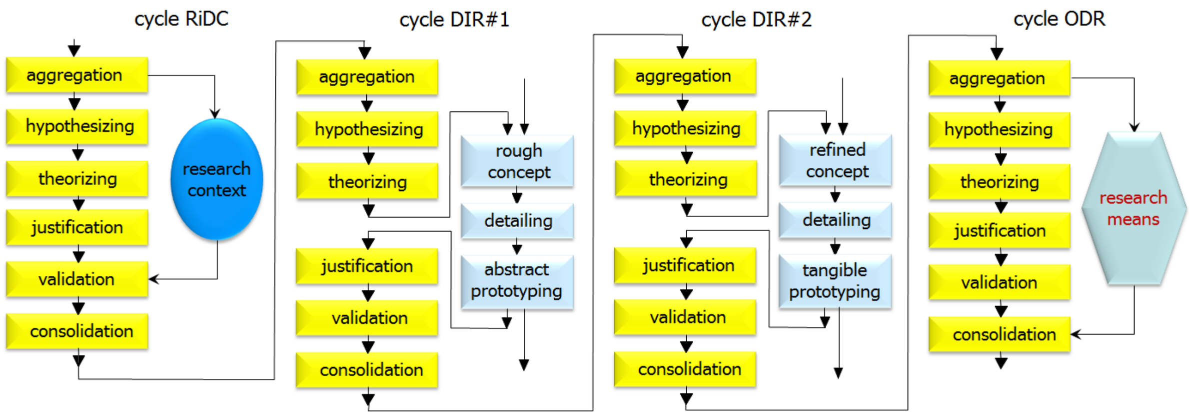

Figure 6 Alternative methodological framing of subsequent research cycles in a research project

Accordingly consolidation may involve both specialization and generalization of the validated knowledge. *Specialization* is concerned with adjustment of the attained knowledge in the same or refined contexts for the subsequent research cycles where, combined with other aggregated knowledge, it is used as input. *Generalization* is concerned with putting the attained knowledge into a broader theoretical context. Towards this end, the new knowledge is decontextualized by means of critical thinking. Its context-dependent parts are peeled off and the limits of validity of the generic kernel of the tested theory are defined. An example of generalization of explanatory knowledge is when knowledge about the experimentally found indicators of driving in haste is used to explain situations where humans should complete activities under time pressure and other procedural constraints. Other form of manifestation of generalization is integration that blends the decontextualized new knowledge with some existing body knowledge with the intention of complementing it and achieving high level coherence and soundness. Obviously, generalization is difficult when the correspondence of the conducted research cycle with the real world situation is weak. This hazard is out there in the case of design research, for all or part of the investigated phenomena may be created as opposed to naturally occurring.

At this point of discussion it seems to be necessary to revisit the *issue of methodological framing* of research cycles, in particular, that of a *design inclusive research* (DIR) cycle (Figure 5). The basic concepts of framing have been published in [6]. It has been claimed that, though logically connected, each and every research cycle is a separate operational unit with own objectives. Research cycles have been casted into various methodological frames corresponding to these objectives in [7]. A possible example of a four-cycle research project is shown in Figure 6. As framing methodologies, research in design context (RIDC), DIR, or operative design research (ODR), reflect a growing level of contextualization. The carrier of the context of research in RIDC is the *reasoning model* of the researcher and it may comprise a set human, artifact, process, environment related information, or any combination of it. In the case of DIR, in addition to this, context information is also carried by the *various prototypes* of the new creations (design manifestations), which are created through three additional stages of constructive actions to serve as a research means. In ODR, in addition to the above two, context information is also carried by the *real life operation*, application and interaction sub-processes, in which various prototypes or final realizations of new creations are used. Hence, in the order of mentioning they support progression from the foundational (disciplinary) domain of inquiry to the operative (practical) domain of inquiry, while facilitating transitivity and specialization. By means of research prototypes, as a dual-face tangible hypothesis, DIR and ODR make it possible to gain access to research data that cannot be obtained and tested without having abstract or tangible implementations [9]. An epistemological concern is that in the ideation, detailing and prototyping stages the body of knowledge represented by the derived theory is combined with some subjective design knowledge and thinking [13]. For this reason, *additional aspects of justification* (e.g. trustworthiness) and validation (e.g. fidelity) are to be taken into consideration in the confirmative part of the DIR cycles.

5 DISCUSSION AND CONCLUSIONS

In the context of scientific inquiry we can talk about *intellectual rigor*. In my view, it has two major constituents, namely formal (conceptual) rigor and procedural rigor. By definition, *formal rigor* is the introduction of high degrees of logical completeness by means of the language and truths of mathematics (logics) by which such proofs can be codified systematically. The main objective is keeping one's intellectual convictions in proportion to one's valid evidence. *Procedural rigor* has different objectives and manifestations. It attempts to achieve balance between the specified scope and objectives of research and demands of thinking procedurally accurately. As such, procedural rigor can be seen as exercise of a skill which can degenerate into pedantry. I presented one *scholarly approach* in this paper that is able to support the procedural part of intellectual rigor by safeguarding the quality of information, enforcing appropriate standard of accuracy, and giving sufficient floor to skepticism.

It is a subject of an on-going debate if design research will be able to achieve rigor of the 'hard' sciences, or should strive after it at all [16]. The central concern for this paper is that, in the reflection of the literature, procedural rigor has not received enough attention in many daily executions of design research and there are no requirements enforced to achieve it. The background research addresses the way in which research can be conducted systematically, rigorously and transparently. Combined with methodological framing, the proposed procedural structuring of research projects supports a rather objective, factual, and critical conceptualization and conduct of inquiry by design research. Though no quantitative requirements and criteria have been formulated (this is left for follow up research), many qualitative criteria have been operationalized in the proposed approach as a whole. It enhances objectivity, reproducibility, rational scrutiny, empirical testability, reliability of theories, as well as justification and validity. The benefits of applying this approach have been observed in more than ten Ph.D. research projects and twenty graduation projects so far.

REFERENCES

Archer, L. B., A view of the nature of the design research, in *Design: Science: Method*, IPC Business Press Ltd., Guilford, Surrey, 1981, 30-47.

Bracht, G. H. and Glass, G. V., The external validity of experiments, *American Education Research Journal*, 1968, 5, 437-474.

Carroll J. M. and Swatman, P. A., Structured-case: A methodological framework for building theory in information systems research, *European Journal of Information Systems*, 2000, 9(), 235-242.

Friedman, K., Theory construction in design research: Criteria: approaches, and methods, *Design Studies*, 2003, 24(), 507-522

Fulcher, A. J. and Hills, P., Towards a strategic framework for design research, *Journal of Engineering Design*, 1996, 7(1), 183-193.

Horváth, I., Comparison of three methodological approaches of design research, in *Proceedings of the 16th International Conference on Engineering Design*, 28-31 August 2007, Paris, 1-11.

Horváth, I., Differences between 'research in design context' and 'design inclusive research' in the domain of industrial design engineering, *Journal of Design Research*, 2008, 7(1), 61-83.

Koch T. and Harrington A., Reconceptualising rigour: The case for reflexivity, *Journal of Advanced Nursing*, 1998, 28(4), 882-890.

Niedderer, K., Relating the production of artefacts and the production of knowledge in research, in *Reflections and Connections: On the Relationship between Creative Production and Academic Research*, University of Art and Design, Helsinki, 59-67.

Owen, C. L., Design research: Building the knowledge base, *Design Studies*, 1998, 19(1), 9-20.

Sanders, E. B.-N., Design research in 2006, *Design Research Quarterly*, Design Research Society, 2006, 1(1), 1-9.

Blessing, L. and Chakrabarti, A., DRM: A design research methodology, Springer-Verlag, Berlin, 2009, 1-397.

Stappers, P. J., Doing design as a part of doing research, in *Design research now: Essays and selected projects*, Birkhäuser Verlag, Basel, 2007, 81-97.

Suppes, P., What is a scientific theory?, in *Philosophy of Science Today*, Basic Book, Inc., New York, 1967, 55-67.

Susman, G. and Evered, R., An assessment of the scientific merits of action research, *Administrative Science Quarterly*, 1978, 23(4), 582-603.

Wood, J., The culture of academic rigour: Does design research really need it?, *Design Journal*, 2000, 3(1), 44-57.