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THE GENERIC DESIGN KNOWLEDGE THAT DESIGN RESEARCH PROJECTS SHOULD PRODUCE

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ABSTRACT

This contribution systematically determines what generic design knowledge should be produced by scientifically conducted design research projects that give a particular design for solving a particular problem, and a particular design method for finding that solution. For this determination I first describe these design research projects within Joan E. Van Aken's account of engineering design research as a science aimed at giving general prescriptive technological rules. Second I derive within this account that the design research projects considered should generate six types of generic design knowledge: three types concern the generality of the application domains of the offered design solution and of the offered design method; two further types concern the efficiency of the design solution and design method; and the final type concerns the expertise that designers should have for using the offered design method.

KEYWORDS

Generic design knowledge, design research methodology, design science, technological rules

1. NOMENCLATURE

A = an aim (a desired state of affairs in the world)

C = a condition (an actual state of affairs in the world)

D = an intervention or artefact

E = design expertise

M = a design method

P = a production process

T = a technological infrastructure

{X}= a class containing X (which may be all of the above) and alternatives to X

2. INTRODUCTION

Engineering design research in academia and elsewhere includes projects that focus on existing or novel problems for exploring if they may be addressed by design. Such design projects may result in a particular design that solves the problem, and in a particular design tool or method by which the offered design can be found. For instance, and this is the running schematised example in this contribution, the problem may be leakages in central heating systems, the design solution a new material for the radiators and piping, and the design method a biomimesis-style search algorithm that makes available biological knowledge about organic bladders, vessels, and the like. Both outcomes of such design projects, assuming that they are valid, represent new design knowledge, which may be captured by the singular proposition that the particular design is a solution to the particular problem considered, and the singular proposition that this particular design can be found by means of the particular identified tool or method.

When engineering design research is taken as a purely instrumental enterprise aimed at finding solutions to problems, this specific knowledge production in terms of the two singular propositions may be taken as sufficient. A design project that generates such a pair of propositions can be taken as concluded: it gives a solution to a problem and, as an extra, provides a tool or method by which this solution was obtained and by which similar problems might be addressed as well. Hence, once the new material for the radiators and piping is found, the design project is concluded, and the subsequent task is to build leakage-free central heating systems.

When, however, engineering design research is considered as a scientific endeavour, and design projects are framed as design *research* projects, this specific knowledge production seems insufficient. Design research projects that are scientifically conducted should produce generic design knowledge and not merely two singular propositions about a design solution and design tool or method. One may then expect that it is also determined whether the proposed tools or methods can address other problems than the one considered. And one may expect more systematic explorations of whether the proposed designs are the only solutions to the problems considered, or whether they are the preferred ones. Is the biomimesis-design method for finding the new material for the radiators and piping also suitable for making, say, cooling systems of engines leakage-free? And are there alternative and better materials that make radiators and piping of central heating systems leakage-free?

In this contribution I assume that engineering design research is a scientific endeavour, and take up the task of systematically determining what generic design knowledge should be produced by design research projects that give a particular design for solving a particular problem, and a particular design method for finding that solution. For this determination I use Joan E. Van Aken's [13] account of engineering design research as a science aimed at giving general prescriptive technological rules. This account is chosen because it defines what design research projects should produce when conducted scientifically, and because it makes visible what such projects fail to provide when merely resulting into a particular design for a particular problem and a particular design method for finding the solution.

Van Aken's account defines in principle also what generic design knowledge design research projects should produce. Yet the characterisation of this knowledge is somewhat generic itself. I therefore analyse this knowledge in more detail, using a procedure for identifying types of knowledge part of this generic design knowledge. This analysis results in six types of generic design knowledge: three types concern the generality of the application domains of the offered design solution and of the offered design method; two further types concern the efficiency of the design solution and design method; and the final type concerns the expertise that designers should have for using the offered design method.

This choice for Van Aken's account of design research is to some extent arbitrary since there exist other accounts that delineates what kind of outcomes scientifically conducted engineering design research should have (e.g., [5,8,12]). I therefore finish by briefly exploring the application of the developed analysis procedure to accounts of design research different to Van Aken's.

By building on an account of what engineering design research produces, the analysis has the advantage of staying close to design research. It determines what generic design knowledge is while focussing on design research, thus avoiding the charge that it imposes epistemic requirements on engineering design research that originate from outside design research (say, from the natural sciences, the humanities, or philosophy of science). If there indeed are *designerly ways of knowing* distinct to ways of knowing advanced in the natural sciences and humanities [3], then a delineation of design knowledge should focus on the way engineering design research is done. Yet, even if designerly ways of knowing are a *sui generis* way of knowing, it still makes sense to see the generation of this knowledge as a scientific endeavour that should meet scientific criteria. Blessing and Chakrabarti [2], for instance, developed scientific methodology for research on and the validation of design methods and tools, and Koskinen et al. [6] discuss the scientific principles of research through design. And both these efforts stay close to design research. This contribution adds to this effort to develop scientific criteria for design research by determining what generic design knowledge may be expected from design research projects. The method I use in this contribution is theoretical and conceptual analysis yet the outcomes are concrete in terms of a list of six types of knowledge that may be required from design research projects. The value of this analysis is that it provides design researchers and their supervisors with a well-defined procedure to determine what generic design knowledge includes. And when Van Aken's account is used, the analysis defines a well-argued list of six types of knowledge that design research projects should produce.

In the next section I start by describing Van Aken's account of design research. In Section 4 I analyse the types of design knowledge a design research project should produce by this account. Then I take distance from Van Aken by arguing in Section 5 for the reasonableness of requiring the six types of knowledge of design projects. In Section 6 it is explored how the developed analysis of generic design knowledge applies to other accounts of designs research.

3. VAN AKEN'S ACCOUNT OF DESIGN RESEARCH AS SCIENCE

The characterisation of engineering design research as design science that Van Aken gives in his [13] is primarily meant as setting a standard for the academic field of management research. Van Aken's complaint about this field is that it has become primarily an *exploratory science* aimed at description, explanation and prediction, and not a *design science* for developing knowledge for the design, improvement and realisation of artefacts for achieving aims. Van Aken wants management research to become useful as well, and therefore sets out to explain to researchers in management what a design science is, drawing from research on design in engineering and architecture. This way of proceeding suggests that Van Aken actually describes the field of design research as it is, and that design research thus is already a science. It is however more accurate to see Van Aken's account of design science as not only normative towards management researchers but also towards design researchers: the account spells out what it means to conduct design research projects scientifically.

Van Aken's account contains three main elements. First design research has the objective of developing valid and reliable prescriptive knowledge about solving problems by design. Second a design solution to a problem in Van Aken's sense has three components: an object design, which is the intervention or artefact that solves the problem; a realisation design, which is a plan to implement the intervention or to produce the artefact; and a process design, which is the plan or method the designer uses for arriving at the solution and the realisation design. Third Van Aken gives a general format for prescriptive design knowledge claims, which he calls technological rules.

The design research projects considered in this contribution fit Van Aken's account partially. These projects give a particular design solution to a particular problem, which counts in Van Aken's account as part of the object design. These projects give also a particular design method to find the design solution, which counts in the account as part of the process design. Hence, by looking in detail at what Van Aken's account requires more from such projects, one can identify what these projects should produce when conducted scientifically.

All three elements of Van Aken's account are relevant for this identification. Design research projects are to generate valid and reliable prescriptive design knowledge. Design research projects should provide all three components of a design solution in Van Aken's sense. And design research projects should cast their knowledge claims in terms of technological rules. I will not discuss here the conditions under which design knowledge can be taken as valid and reliable.[1] The task taken up in this contribution is to systematically delineate what generic design knowledge should be produced by design research projects, and it is presupposed that this knowledge is valid and reliable. I therefore focus on spelling out the content of the second and third elements of Van Aken's account, and these elements are discussed in reverse order.

3.1. Technological rules and algorithmic prescriptions

In his characterisation of scientific design research Van Aken combines colloquial descriptions with more formalised ones. According to Van Aken, design research aims at *technological rules*, and he defines a technological rule in colloquial terms as ([13], p. 228):

> [A] chunk of general knowledge, linking an intervention or artefact with a desired outcome or performance in a certain field of application.

Technological rules are not particular prescriptions for particular situations, but "a general prescription for a class of problems" ([13], p. 228). For capturing this generality, Van Aken makes a distinction between heuristic prescriptions and algorithmic prescriptions. A *heuristic prescription* is a general prescription that does not solve a particular design problem but that has to be translated to a particular problem for finding a particular solution to it. And when translated to a particular problem, one obtains an *algorithmic prescription*, which gives a particular solution to a particular problem. Van Aken also gives more formal descriptions of both heuristic and algorithmic prescriptions. Heuristic prescriptions can have the form ([13], p. 227):

> [I]f you want to achieve Y in situation Z, then something like action X will help,

where the phrase "something like action X" refers to a general type of actions X that has different

[1] See, e.g., [2,4,11,14] for design knowledge validation, in addition to Van Aken's [13] and the sources he discusses.

particular variants. Algorithmic prescriptions have the form ([13], p. 227):

> [I]f you want to achieve Y in situation Z, then perform action X,

where “action X” refers to a particular action.

The above more formal description of a heuristic prescription captures the generality of technological rules with respect to the action X, yet does not capture their generality with respect to the problem addressed, being to achieve Y in situation Z. For including also this latter generality of technological rules one can extrapolate Van Aken’s formulations, and represent technological rules by heuristic prescriptions of the form:

> If you want to achieve something like goal Y in situations like Z, then something like action X will help.

And when this heuristic prescription is translated to a particular problem and solution, one obtains again the algorithmic prescription:

> If you want to achieve Y in situation Z, then perform action X.

For readability I use in this contribution even more compact forms for both types of prescriptions. For technological rules I use:

> Technological rules:
>
> {X} realise {Y} in {Z}.

The sets {X}, {Y} and {Z} refer to classes of particular actions, particular goals and particular situations. A translation of a technological rule to particular actions, goals and situations, then give algorithmic prescriptions captured by:

> Algorithmic prescriptions:
>
> X realises Y in Z.

3.2. Object, realisation and process design

Van Aken discerns in design research three types of design knowledge: knowledge about object design, knowledge about realisation design and knowledge about process design. The *object design* is the design of the intervention or artefact itself by which a specific aim can be achieved. The *realisation design* is the design of the plan for the implementation of the intervention or for the actual production of the artefact. The *process design* is the method used to design a solution to a problem and to design a realisation plan for this solution ([13], p. 226). In terms of the earlier example, the object design is the new material for the radiators and piping, the realisation design the plan to create this material and build the radiators and piping with it, and the process design includes using the biomimesis-design method.

For capturing these three types of design knowledge in terms of technological rules and algorithmic prescriptions, I introduce some notation. Consider first object design. Let D be the result of the object design, that is, the intervention or the artefact. Let A be the aim to be realised with the object design, and let C refer to the conditions of the situation in which the aim should be realised. In terms of the example, D are radiators and piping consisting of the new material, A is a leakage-free central heating system, and C standard conditions in buildings in which heating systems are to be employed. The technological rules and algorithmic prescriptions associated to object design then have the formal form:

> Object design technological rules:
>
> {D} realise {A} in {C}.
>
> Object design algorithmic prescriptions:
>
> D realises A in C.

Consider second realisation design. Let P be the plan for producing D and let T refer to the available technological infrastructure for production. P can thus be the plan to construct the new material and the radiators and piping with it. And T consists then of the current industrial infrastructure and engineering expertise available to operate industrial plants. The technological rules and algorithmic prescriptions associated to realisation design then have the form:

> Realisation design technological rules:
>
> {P} produce {D} in {T}.
>
> Realisation design algorithmic prescriptions:
>
> P produces D in T.

Consider finally process design. Let M be the methods that organises the processes involved in creating object designs realisation designs, and let E be the expertise the designers involved have. In the example M thus is the biomimesis-design method complemented with regular manufacturing methods. The technological rules and algorithmic prescriptions associated to process design then have the formal form:

Design method technological rules:

{M} find {DforAinC & PforDinT} with {E}.

Design method algorithmic prescriptions:

M finds DforAinC & PforDinT with E.

DforAinC and PforDinT are shorthand for an object design algorithmic prescription and for a realisation design algorithmic prescription.

4. GENERIC KNOWLEDGE FOR DESIGN RESEARCH PROJECTS

Consider again the design research projects focussed on in this contribution. In terms of the above terminology such projects produce only two algorithmic prescriptions: an object design algorithmic prescription that a particular design D realises a particular aim in particular conditions, and a design method algorithmic prescription that a particular method M leads to this particular object design:

D realises A in C.

M finds DforAinC with E.

With Van Aken's account of scientific design research it is also clear that by these outcomes the design research projects are not providing full generic design knowledge: technological rules associated to the object design and process design are lacking; and realisation design knowledge is altogether missing.

In principle the task taken up in this contribution is now realised: the generic design knowledge the considered design research projects should produce are, in addition to the two above algorithmic prescriptions, these the technological rules associated to the object and process designs, and the algorithmic prescription and technological rule associated to the realisation design. This characterisation of the missing design knowledge is however quite generic itself. For analysing what it includes, I therefore use a procedure to identify types of knowledge part of this missing generic design knowledge. This procedure consists of considering what kind of knowledge partial generalisations of the algorithmic prescriptions represent. Take, for instance, the object design algorithmic prescription "D realises A in C". A partial generalisation of this prescription is a generalisation with respect to only one element, say D, while keeping the others fixed, leading to a 'truncated' technological rule, in this case "{D} realise A in C". By evaluating such partial generalisations of the object design and design method algorithmic prescriptions, one can identify six different types of design knowledge in the generic knowledge that is to be produced by design research projects that end with a design D realising aim A in conditions C, and with a method M for finding this design.

For readability, I spell out in this section only the partial generalisations of the algorithmic prescriptions for object design and process design; a similar discussion for realisation design is given in the appendix to this contribution, and its results are summarised at the end of this section.

4.1. Generic object design knowledge

Consider the object design algorithmic prescription provided by a design research project as considered:

D realises A in C.

Full knowledge of the object design would require that the technological rule "{D} realise {A} in {C}" is given that generalises this algorithmic prescription with respect to all three elements D, A and C. But, as announced, I generalise the object design algorithmic prescription only with respect to one element at a time. So consider first the knowledge represented by the 'truncated' object design technological rule obtained by generalising over only the design solution D:

{D} realise A in C.

This rule represents knowledge about other designs {D}/D that can realise A in C. In terms of the running example: other materials or altogether different radiators and piping that also amount to non-leaking central heating systems. Such knowledge, though not directly about the design D as given by the project, nevertheless is a preamble to efficiency claims about this design D. In a design project it may be established that D is an effective solution to achieve A in C, yet efficiency is in design research a central value as well, meaning that it should also be established that D is the best solution compared to readily available alternatives: D should be a satisfactory and a *satisficing* solution to realising A in C [12]. So the first truncated technological rule identifies knowledge the design project should provide for establishing the efficiency of the design D it proposes.

Consider second the knowledge captured by the truncated object design technological rule:

D realises {A} in C.

This rule represents knowledge about other aims {A}/A that can be realised with D given conditions C. The material designed may also be usable for creating waterproof packaging, or may, more unfortunately, ignite when mildly heated. The second truncated technological rule thus represents knowledge the design project has to generate to give the application domain of the design D in terms of the various aims that can be realise with D, including possibly unintended ones.

Consider finally the knowledge captured by the truncated rule:

D realises A in {C}.

This third rule represents knowledge about other conditions {C}/C that also allow realising A with D. The material may be useful for non-leaking radiators and piping also under, say, artic circumstances at which the water contained in the radiators and piping regularly freezes. This determination of alternative conditions C for which the design solution D works, again contributes to knowledge about the application domain of D but now in terms of its robustness, i.e., in terms of the conditions under which D can realise the intended aim. Hence the third truncated technological rule also represents knowledge the design project has to generate to give the application domain of the design D.

4.2. Generic design methodological knowledge

Let us move to the design method algorithmic prescription containing the design method M proposed in the design research projects considered:

M finds DforAinC with E.

Consider again the knowledge represented by the truncated technological rules obtained by separately generalising over the different elements in this algorithmic prescription. The first truncated rule is:

{M} find DforAinC with E.

This rule represents knowledge about other methods {M}/M that allow designers with expertise E to find the design D for realising aim A in conditions C. Returning to the running example: biomimesis may lead to finding the material for non-leaking radiators and piping, yet others methods may as well. Moreover, if these other methods are more conventional design methods, then invoking biological knowledge about organic bladders, vessels, et cetera, may be sophisticated and innovative, yet also unnecessary and overly complicated. This knowledge about alternative methods for finding D therefore can be seen as revealing the rationality or efficiency of using M for finding D, and the design research project should produce this knowledge for establishing the efficiency of the method M it sets forward.

The second truncated technological rule for the process design is:

M finds {DforAinC} with E.

This rule represents knowledge about which other object designs {DforAinC}/DforAinC can be realised with M given E. The biomimesis-design method may also be of use to making cooling systems of engines leakage-free, or to, say, finding materials that extract water from fluids and mixtures. This knowledge determines the application domain of the design method M by delineating which object designs it can help to find, and should again be produced by the project if it is to provide knowledge about the application domain of the method M it provides.

The third truncated technological rule reads:

M finds DforAinC with {E}.

It represents knowledge about the expertise needed for using the proposed method M effectively: E may be sufficient, yet alternatives in {E} may be sufficient as well, making explicit what minimally is required from the designers to use M. In the project on leakage-free central heating it may, for instance, be assumed that the designer has to have some basic experience with biology. Yet, by considering alternative expertise this may turn out to be not necessary. This knowledge therefore makes explicit what expertise the method M requires from a designer, and should be provided by the project as part of specifying this method M.

4.3. Generic realisation design knowledge

In the Appendix it is considered what types of generic knowledge may also be required from our design research projects when realisation design is included. In short this implies three types of knowledge:

- knowledge about alternatives {P}/P to a realisation design P for producing D in T, i.e., knowledge about the efficiency of the proposed realisation design P.
- knowledge about other object designs {D}/D that can be produced by P in T, i.e., knowledge about the application domain of the realisation design P.
- knowledge which technological infrastructure is necessarily needed for producing D with P.

5. SIX TYPES OF GENERIC DESIGN KNOWLEDGE

By means of Van Aken's account of engineering design research, six types of generic design knowledge were identified that can be expected from design research projects generating a design and a method to find that design (I again ignore the types of knowledge associated to realisation design). And in case Van Aken's account does not convince the reader, alternative argumentation can be given in favour of this conclusion. The six types of knowledge may be grouped under headings expressing familiar values for engineering design research. Hence, when accepting these values, each identified type of generic design knowledge can again be required from the design research projects considered. For showing this I group the types of knowledge, ignoring the order in which they were derived.

Three types of generic design knowledge can be taken as knowledge about application domains:

> **Application domain knowledge** about the results of design research projects:
>
> Type I. Knowledge about the aims {A} that can be realised with the proposed design D in conditions C, including possible unintended aims.
>
> Type II. Knowledge about the conditions {C} that should be in place for the proposed design D to realise aim A.
>
> Type III. Knowledge about the object designs {design D realises aim A in conditions C} that can be found with the proposed design method M.

Van Aken [13] stresses in his account that design research projects should generate generic knowledge about object designs, and type I and II knowledge are capturing that generality. By also identifying type III knowledge as generic design knowledge, the analysis in this contribution extends that generality from the object designs to the design methods that design research projects give.

Two further types of generic knowledge may be grouped under the heading of efficiency:

> **Efficiency knowledge** about the results of the design research projects:
>
> Type IV. Knowledge about the efficiency of the proposed design D, relative to other designs, to realise aim A in conditions C.
>
> Type V. Knowledge about the efficiency of the proposed design method M, relative to other design methods, to find design D to realise aim A in conditions C.

Efficiency with respect to the design solution is an obvious value in engineering design research, and probably most visible in design for incremental improvements. Efficiency with respect to design methods is a value as well, specifically in more industrial contexts since designers and the time they need for coming up with solutions are expensive.

The final type of generic design knowledge may be taken as knowledge about the qualifications designers as users of methods should meet:

> **Designer qualification knowledge** about the results of the design research projects:
>
> Type VI. Knowledge about the expertise designers have to have for using the proposed method M.

In engineering design research there is ample interest in design expertise, often related to the question of how design should be taught. The achievements of expert designers and novices are, moreover, regularly contrasted in research, in part for determining what expertise expert designers have and should be transferred to the novices (e.g., [3,7,10]).

In terms of the running example of resolving leakages in central heating systems: if such a project is concluded with a new material for the radiators and piping, and with a biomimesis design method, then Van Aken's account of design research or values part of design research require that this project not ends with just these two outcomes. Such a project should generate also knowledge about the application of the material and method: type I knowledge about alternative uses of the material; type II knowledge about the range of conditions under which the material, when used in radiators and piping, indeed makes heating systems leakage free; and type III knowledge about the domain of (other) design problems for which the biomimesis design method can be used as well. Moreover, such a design project should give type IV knowledge about how efficient the material makes central heating systems leakage-free as compared to other available solutions. And it should give type V knowledge about how efficient the biomimesis method is in finding the proposed material. Finally the project should produce type VI knowledge about the expertise designers need to have for applying the biomimesis design method.

6. CONCLUSION AND DISCUSSION

In this contribution I took up the question what generic design knowledge should be generated by scientifically conducted design research projects leading to a design and a method to find that design. For this determination Van Aken's account of engineering design research was used for defining what outcomes design research projects should produce. These outcomes are precise algorithmic prescriptions and generalisations thereof, called technological rules. I analysed the knowledge about these rules through partial generalisations of the algorithmic prescriptions, leading to identifying six types of generic design knowledge that design research projects should produce.

This approach to systematically determine types of generic design knowledge for design research projects has been applied together with Van Aken's account of design research. In principle it can also be applied to other general accounts of design research (e.g., [5,8,12]). If such an account describes an outcome of a design project in terms of a number of variables $\langle X,Y,Z,\dots\rangle$ (e.g., X is a functional design, Y is a prototype, et cetera), then applying the approach means determining the types of knowledge represented by the partial generalisations $\langle\{X\},Y,Z,\dots\rangle$, $\langle X,\{Y\},Z,\dots\rangle$, et cetera, and taking them as generic design knowledge design research projects should produce.

With Van Aken's account six types of generic design knowledge were determined in this way. These six types are related to values part of design research, hence, they may be required from design research projects even when rejecting Van Aken's account.

The six types of knowledge are:

Application domain knowledge:

Type I. Knowledge about the aims {A} that can be realised with the proposed design D in conditions C, including possible unintended aims.

Type II. Knowledge about the conditions {C} that should be in place for the proposed design D to realise aim A.

Type III. Knowledge about the object designs {design D realises aim A in conditions C} that can be found with the proposed design method M.

Efficiency knowledge:

Type IV. Knowledge about the efficiency of the proposed design D, relative to other designs, to realise aim A in conditions C.

Type V. Knowledge about the efficiency of the proposed design method M, relative to other design methods, to find design D to realise aim A in conditions C.

Designer qualification knowledge:

Type VI. Knowledge about the expertise designers have to have for using the proposed method M.

One may criticise in two ways the identification of these six types of knowledge as generic design knowledge. First, one may criticise it as being hardly exhaustive. Already Van Aken's account gives more types of generic design knowledge, as, for instance, the types related to realisation design. Additionally one may argue that design research projects should provide knowledge about the skills users should have for using design solutions (analogous to knowledge of type VI), as well as knowledge about the usability and safety of the design solutions for users.

Other values in design research may define further types of design knowledge to be required from the design research projects considered in this contribution. Innovativeness and intellectual property are such values, leading to types of knowledge about patents related to the design solution, both positive – what sets the design solution apart, and what patents can be claimed with it? – and negative – which existing patents can block the realisation of the design solution? Societal and commercial acceptability are, moreover, also values in design research, leading to demands for knowledge about compliance of the design solution to national and international law, about its sustainability and about its economic viability. Hence, there are more types of knowledge to be required in design research than the six described in this contribution.

Second, one may criticise the list of six types of generic design knowledge as being way too extensive and demanding. Requiring all six types of knowledge from design research projects makes that these projects become too complicated and too time-consuming, obstructing a viable practice. Design projects can lead to various useful design solutions to all kinds of problems, and the pace by which these solutions are made available is unnecessarily slowing down by requiring knowledge about alternative solutions and alternative methods. Projects advancing a design method become, for instance, rather open-ended when researchers have to determine what object designs can be found with the method (knowledge of type III) and have to compare the method in terms of its efficiency with rival methods (knowledge of type V). Taking design projects as scientific research thus seems to jeopardize their output and feasibility.

A proper response to the first criticism of non-exhaustiveness is one of acceptance: given the context of design research projects all kinds of further requirements can be relevant to the projects, extending the epistemic demand to other types of knowledge.

A strict response to the second criticism is that scientific research indeed requires additional work. When design research is taken as merely instrumental to finding solutions to problems, this additional work may be skipped and design research may remain to consist of swift and pragmatic projects. Yet, this swiftness comes with a price. In design research there are complaints that the field is fragmented in separate strands where researcher belonging to one strand hardly (can) use the results of researchers belonging to another (e.g., [1,2,9,15]. Building up a coherent, unfragmented body of design knowledge takes time, and involves painstaking research using scientific research methods by which each individual proposal is validated and compared to rival proposals [2].

A milder response may be that if design research is to evolve towards this coherent scientific body of design knowledge, researchers and their supervisors should be aware of what it takes to conduct a design research project scientifically. Merely presenting a new design solution and a design method or tool to find that method does not do, because those outcomes do not give the six types of generic design knowledge identified in this contribution. Also providing more design solutions with the method presented will hardly do, since this may provide a bit more knowledge of type III but not, say, knowledge about alternative aims that can be realised with the design solutions (knowledge of type I) or about the efficiency of the method (knowledge of type V). For doing design research projects scientifically, these projects should result also in claims or conjectures about the application domains of the design solutions and design methods, of their efficiency, and of the expertise designers should have to use the methods.

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APPENDIX

With Van Aken's account it follows that a design research project that ends with a design D and a method M for producing D should also produce a realisation design P for D. If this demand is incorporated in the determination of what generic knowledge may be required from such a project, then the analysis as given in Section 4 starts with three algorithmic prescriptions, including one – the second – for the realisation design:

D realises A in C.

P produces D in T.

M finds DforAinC & PforDinT with E.

Generalisations of these algorithmic prescriptions to truncated technological rules proceeds similarly as in Section 4, and yields for the first object design algorithmic prescription the same results as described in Section 4.1. The algorithmic prescription for realisation design is now added, and leads to the identification of new knowledge types that a design research project should produce. For the third design method algorithmic prescription, this determination changes somewhat as compared to the analysis given in Section 4.2 since it now also contains the realisation design 'PforDinT' as an element.

Consider first the new algorithmic prescription for the realisation design. The truncated technological rules obtained by partial generalisations are:

{P} produce D in T.

P produces {D} in T.

P produces D in {T}.

The first truncated rule represents knowledge about alternatives {P}/P to P for producing D in T, which is knowledge about the efficiency of the realisation design P.

The second rule represents knowledge of other object designs {D}/D can be produced by P in T, which is knowledge about the application domain of P.

The third rule represents knowledge which technological infrastructure is necessarily needed for producing D with P.

Consider now the design method algorithmic prescription:

M finds DforAinC & PforDinT with E.

The truncated technological rules are:

{M} find DforAinC & PforDinT with E.

M finds {DforAinC} & PforDinT with E.

M finds DforAinC & PforDinT with {E}.

The first truncated rule represents knowledge about alternative methods for finding D and P, revealing the rationality or efficiency of the design project's outcome to specifically use M for these purposes.

The second rule represents knowledge about the application domain of the design method M, now with respect to both object and realisation designs.

The third rule represents knowledge about the design expertise E required for using the method M for the object and realisation designs.