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ASSESSING DESIGN RESEARCH QUALITY: INVESTIGATING VERIFICATION AND VALIDATION CRITERIA

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ABSTRACT
Engineering design research spans many disparate approaches to study, from simulation to case studies. A challenge for the community is to ensure and evaluate the research quality, taking into account the variety of approaches. This paper explores four classes of evaluation criteria, truth value, applicability, consistency, and neutrality, based on interdisciplinary research literature. These are decomposed into several elemental metrics and distinguished by validation or verification type. The metrics are applied to two reported research studies (empirical and simulation) on similar topics. In the comparison, it is found that the authors of both papers explicitly addressed validation related criteria on the results of the research. However, the empirical study authors also included more details on the verification based metrics as they relate to the research process. The issue of how the verification and validation criteria can be operationalized according to the research method is identified as critical future research.

Keywords: verification, validation, empirical research, case study, simulation, research assessment

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1 HOW CAN WE EVALUATE RESEARCH?

The purpose of this paper is to explore a set of metrics that can be used to compare, select, and define research methods within engineering design. This is motivated from personal challenges in advising our students in how to plan, structure, and evaluate their own research. This challenge is further exposed when offering a new graduate level course in advanced research methods at Grenoble University where students are introduced to research tools such as case study and simulation; seemingly disparate and distinct approaches to developing new knowledge. A second motivation derives from our frustrations within the community in discussing what are seemingly different concepts of research validation yet, which, in our opinion, are fundamentally similar. This motivation is compounded by our frustrations in communicating the impact and relevance of our research with colleagues outside of the engineering design community where we might use the same terminology, but with fundamentally different meanings or we might use different words but with essentially the same semantics. These motivations lead us to believe that there is a distinct need to study the research methods that are employed in engineering design research, in addition to executing the research itself. Thus, we want to answer the following question:

What criteria can one use to characterize and qualify their design research?

Rather than selecting a single metric for evaluating the quality of design research, we believe that a set of metrics should be used to explore different aspects, much as we offer many approaches to complexity measurement in design rather than integrating into a single metric. Thus, the aim of this paper is to explore various approaches on how to increase the confidence of the quality of the research based on the research methods.

While there are numerous different research approaches and tools, we identify four general classes here: case study, protocol study, experimental study, and simulation study. These classes are not intended to be mutually exclusive. Case studies are defined as objective, in-depth examinations of uncontrolled, contemporary, and complex phenomenon (Teegavarapu et al., 2008; Yin, 2003). The objectivity of cases is derived from the fact that they are studied without direct influence on the performance or execution of the process. Typically, case studies might span multiple months, if not years. Protocol studies explore complicated design behaviors and activities within a controlled environment, but with a predefined analysis protocol (Jiang and Yen, 2009; Sen and Summers, 2012). The scope of the research is more limited to looking at activities with durations on the order of hours and focus on understanding the detailed behaviors of a few individuals. Experimental studies in engineering design research focus on comparison of methods and fine tuning tool and method parameters, such as those found in idea generation or design reviews (Hernandez et al., 2010; Linsey et al., 2005). Finally, simulation studies in engineering design focus on mathematical modeling of design processes and activities with computational agents serving as surrogates for the human actors (Chao et al., 2002; Kannapan and Marshek, 1992).

To help illustrate this, we introduce two papers here where the researchers each studied failure evaluation in early stage engineering design, but from two different research approaches: empirical studies (Marini et al., 2011) and simulation studies (Papakonstantinou et al., 2012). Table 1 compares the two papers based on content and citations.

Table 1: Comparison of Empirical and Simulation Study Papers

	Empirical Study (Marini et al., 2011)		**Simulation Study** (Papakonstantinou et al., 2012)	
	Section Size Ratio	**Citation Ratio**	**Section Size Ratio**	**Citation Ratio**
Background	1.5 pages / 8 pages (~20%)	30/37 (~80%)	3 pages / 7 pages (~45%)	34/35 (97%)
Research Method	1.5 pages / 8 pages (~20%)	7/37 (~20%)	2.5 pages / 7 pages (~35%)	1/35 (3%)
Research Results	4 pages / 8 pages (~50%)	0/37 (0%)	1.5 pages / 7 pages (~20%)	0/35 (0%)
Comparison to Other Work	1 pages / 8 pages (~10%)	4/37 (~10%)	0 pages / 7 pages (~0%)	NA

These two papers are selected as representative of the two general classes of research, are generally current as they have been published within the past two years, and are topically external to research areas of interest of the authors. The papers are drawn from the two largest and most prominent engineering design research conferences, ASME's *IDETC/CIE* and the Design Society's *ICED*. The purpose of this comparison is to start a discussion concerning the differences and similarities with respect to qualification of the research approaches. This comparison is not intended to be a statistical survey, but illustrative. We are not comparing the value of the respective research findings, nor do we evaluate the quality of the research itself. These two are selected based on similar topical coverage.

The goal of the empirical study is to study "how design flaws motivate the rejection of alternatives, and how the influence design feedback" (Marini et al., 2011). To address this, the researchers have conducted a 2.5 year longitudinal case study set within a medical device production firm. This case study included 17 presentations, 5 technical reviews, 14 feasibility reports, 4 matrices on set-based design, evaluation reports, sketches, 50 CAD variants, 9 system models, 61 working principle models, 5 open ended interviews, and 3 semi-structured interviews. The authors focus on explaining the details and the extensiveness of the data collection to build confidence in the work. The patterns found in the case study were explicitly compared against other case studies in automotive, energy, and chemical companies. The results and findings were tied directly to the documents studied in the case study. The authors offered a justification for this approach to the research (case analysis).

The second paper has the stated goal of "semiautomatic reliability analysis of design configurations". The authors provide a case study of a boiling water nuclear reactor system as simulated through their FFIP (Functional Failure Identification and Propagation) framework. The authors emphasize the demonstration of their simulation tool without any benchmarking to other systems. Less than a quarter of the paper is dedicated to results from the simulation studies. The authors do not explicitly offer any justification for this type of research.

As these are both examples of research reported in design conferences, they are not necessarily comprehensive in their explanations, but are reporting on recently completed work that might fall within a broader research context. However, each provides us with useful insights into the importance placed on different aspects of the research as presented. This importance might be related to the scopes and aims of the research communities in which they are presented, but it is more likely that the relative importance is based on the selected research methods employed. The papers are evaluated (Section 4) with respect to how they address different metrics on the research with respect to validation and verification (Section 3) as related to the goal of studying engineering design (Section 2).

2 WHAT IS THE SCOPE OF DESIGN RESEARCH?

Design research studies the design process; it is not the activity of gather user requirements and other background information to execute a development project. If we examine the aims and scope or prestigious design journals (*Design Studies*, *Journal of Engineering Design*, *Journal of Mechanical Design*, or *Research Engineering Design*), all explicitly refer both to fundamental knowledge and applied practice with an implicit aim to study design in support of practice (Blessing and Chakrabarti, 2009). This is emphasized in the DRM by the significance given to Prescriptive Study (Blessing and Chakrabarti, 2009) and also by the study of the emerging field realized in studying ICED proceedings (Cantamessa, 2003). The resulting classification is based on research objectives (Cantamessa, 2003):

- *Empirical Research* (EM): analysis of real-world design process and practice.
- *Experimental Research* (EX): study of design process in controlled environment.
- *Development of New Tools* (NT): development of tools to support design process or activity.
- *Implementation Studies* (IS): study of deployment of NT to real-world situations
- *Other* (OTH): study dedicated to theory and education

In the ICED study, while half the papers were about developing a new tool or method (NT), the empirical research (EM) in design still accounts for 20% of the papers. EM includes both qualitative case studies and quantitative surveys. EX papers was still a limited number, but increasing from 5% to 10% for the study. IS related to field works are a small portion of the papers (about 14%) that illustrate the expected impact of researchers in the design practices. This study showed the tendency of the design research area where a wide variety of research methods from various disciplines has to be used to investigate the multiple facets of design. However, the distinction between EX and EM is not stable within the community. If EX deals with controlled environment, EM can be run in artificial design situations in the sense they are designed by researchers. Some authors present design observations (Hicks et al., 2009; Torlind et al., 2009) as taking into account all variables that cannot be controlled in studying complex design tasks even in lab environment. The concept of experimentation, emphasizing reproducibility and variable control, attempts to ensure objectivity in the data gathering and analysis.

EM is often suspected of subjectivity, when the distance between the researcher and the object under study is not clearly identified. For this reason, the evaluation of research quality is difficult, as is found in other disciplines, such as operations management (Karlsson, 2009) and education research (Howe and Eisenhart, 1990; Salomon, 1991).

The research methods for qualitative and quantitative research derive from different disciplines, introducing additional contextual problems for researchers in design. For instance, qualitative research derives primarily from social sciences and their developed methods, while quantitative research is currently the dominant research perspective based on the engineering training in physical sciences. This perspective includes the belief of positivism that considers the reality exists as “knowledge is context free” (Karlsson, 2009) and exists “out there” i.e. independent of the research context or belief or assumption of the researcher (Klein and Lyytinen, 1985). Quantitative research generally employs quantitative methods to describe and explain phenomena such as optimization models, simulation, surveys and laboratory experiment (Meredith, 1998). Quantitative is more consistent with the engineering background of a lot of researchers of the area, using numbered data and statistics or mathematics to analyze them. Objectivity is benefited from formal tools reducing the interpretative dimension that one consider as subjectivity to be avoided. Qualitative research uses a naturalistic approach and is described as “the study of the empirical world from the viewpoint of the person under study” (Schmidt, 1981). Qualitative research aims to understand how and why events occur in real world setting (Yin, 2003). The quantitative researcher considers temporal and contextual aspects of the contemporary phenomenon under study but without experimental controls or manipulation (Meredith, 1998). This field research can employ both quantitative and qualitative methods such as interviews or observations to collect and analyze the empirical data. A quantitative method to gather data can be the use of unobtrusive measures which rely on objective evidence (Webb et al., 1996). For example, in product development the activity of knowledge sharing can be measure by the number of boundary artifact exchanged between members of a team project through the PLM system. Figure 1 illustrates a notational comparison between qualitative and quantitative research based on the clarity of the boundaries and the resolution of study. Quantitative research has a smaller focus and research resolution, its system boundaries are better defined, and the environmental interfaces are known and controlled. Qualitative research, however, typically is concerned with a larger research scope and resolution of inquiry, has less rigid boundaries specified, and the environmental interfaces are typically unknown and under investigation in the research.

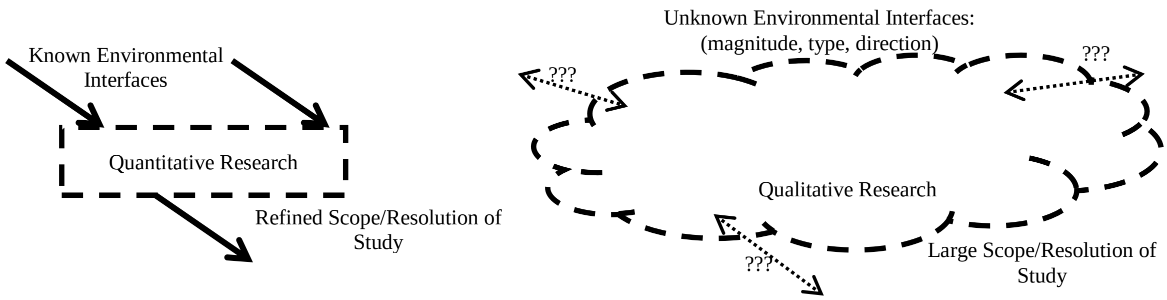

Figure 1:Quantitative vs. Qualitative Research (boundary definition, interface, and scope)

The Table 2 maps the DRM stages (Blessing and Chakrabarti, 2009) to Cantamessa’s typology (Cantamessa, 2003) through the research methods (case study, protocol study, experimental study, and simulation). Table 2 relates the different methods that researchers can adopt to address the objectives of each Cantamessa’s research type according the DRM stages. For example, in EM, case studies can be used as explorative tools to help identify and define research objectives and questions or develop research propositions. In IS, case studies can also be used. However, the goal of the case study is to understand how the newly developed and introduced tool influences the real world situation. For this reason, the ES and IS research align well with the DS I and DS II classifications in DRM process (Table 2). In operations management field, authors refer to theory building and theory testing objectives (Meredith, 1998), which are not entirely covering the previous category but have a lot of commonalities in the purpose. Table 2 also classifies the type of research; while ES and IS are more qualitative oriented addressing a large scope of study, EX and NT scopes are more refined and allow more quantitative approaches.

Table 2: Mapping of Research Classifications

Type	Scope of Study	Stage of DRM			Classification	
		DS I	PS	DS II	Qualitative	Quantitative
EM	Product Development Process	Case Study			++	+
EX	Design Task	Protocol Study	Experimental Study	Protocol Study	+	++
NT	Design Tool		Experimental Study Simulation	Protocol Study	+	++
IS	Product Develop Process with Tool			Case Study	++	

From the table, it is shown that qualitative and quantitative research methods are found throughout the typology of research and the stages of DRM. This suggests that there is need for both types of research methods, but also a coordination and understanding between researchers employing each type. For this shared understanding, it is important that the researchers clarify the criteria to evaluate their research both in the findings and in the research approach.

3 WHAT ARE THE METRICS?

In literature, the issue of the evaluation of research quality is closely related to the epistemological research. Many scholars of research belief that quantitative research are more appropriate for testing or verifying existing theory while qualitative research such as exploratory and descriptive case studies are best for generating new theory or extending theory by including new factors (K M Eisenhardt, 1989; Meredith, 1998; Richardt and Cook, 1979). As the purpose of those two research approaches and the researcher implication in the research process are essentially different (Table 3) is it relevant to use the same metrics to evaluate the research quality? When judging qualitative research, the “usual canons of ‘good science’ require redefinition in order to fit the realities of qualitative research” (Strauss and Corbin, 1998). However, quantitative and qualitative researchers have to demonstrate that their research quality by meeting the requirements for rigor. While the quality in quantitative research depends on the instrument construction, in qualitative research the researcher is the instrument (Patton, 2002). Qualitative research contribution is largely determined by its design quality but also by the researcher’s analysis (McCutcheon and Meredith, 1993).

In quantitative research, the reliability and the validity are the two traditional criteria used to demonstrate the research credibility. For qualitative researchers, the criteria generally used in place of reliability and validity is “t*rustworthiness*” (Guba, 1981). This term enables to demonstrate both rigor of the research process and the relevance of the findings. (Guba, 1981) has proposed a model for assessing the trustworthiness based on four aspects that are relevant to both quantitative and qualitative research: truth value, applicability, consistency and neutrality. Each dimension must be defined differently for quantitative and qualitative research based on the conceptual divergence of the two approaches. Table 1 presented the definition of the criteria and their comparison.

From a positivist point of view, reliability refers to the repeatability of the results. It has been argued that the best way to test theories is to make repeated controlled observations and replicable settings (Kuhn, 1970). This concept in case study research is defined as “the extent to which a study’s operations can be repeated with the same results” (Yin, 2003). For quantitative researchers, the same case conditions can never be fully duplicated in another situation. For this reason, they prefer used the concept of *dependability* (Lincoln and Guba, 1985) which refers more to the repeatability of the research process and its implementation. Dependability is then an assessment of the quality of the integrated processes of data collection, data analysis, and theory generation. In action research, (Checkland and Holwell, 1998) introduced a similar criterion. They stated that researchers must at least achieve a situation in which their research process is *recoverable* by anyone interested in subjecting the research to critical scrutiny. Thus, to address the dependability issue, the research process should be reported in details enabling another researcher to repeat the work but not necessary obtaining the same results. In this respect, qualitative researchers have to clearly explicit the different elements permitting the discussion concerning produced knowledge. This explication concerns for example the conditions of data collection and data analysis, the description of the theoretical concepts used in the research and the justification of their relevance and coherence relating to the data gathered in the field setting.

Table 3: Trustworthiness Model and Comparison of Criteria by Type of Research (adapted from (Guba, 1981) *and* (Lincoln and Guba, 1985)*)*

Trustworthiness dimensions	**Quantitative research**		**Qualitative research**	
	Perception of Reality			
	Reality exists as truth		Reality is dependent upon the individual	
	Research Purpose			
	Explain, predict, verify phenomena occur in word where "Knowledge is context free" (Karlsson, 2009) *Theory Testing: Test existing theory, or causal relations, predict future outcomes, explore impact of variable changes, optimize configuration*		Understand how and why events occur in real world setting (Yin, 2003) *Theory Building or extension: Identify key factors or new factors, describe their linkage and why these linkage exist*	
	Usual criteria	**Definition**	**Usual criteria**	**Definition**
Truth value *Ability to establish confidence in truth of the findings* (Lincoln and Guba, 1985)	Internal validity	Extent to which the causal relationship are certifiable (Yin, 2003)	Credibility	Extent to which the results appear to be adequate representations of the situation under study (Lincoln and Guba, 1985)
Applicability *Ability to generalize from the findings to other contexts or settings*	External validity Generalization	Extent to which findings draw from studying one group can be generalized or applied to other groups or settings (McCutcheon and Meredith, 1993)	Transferability	Extent to which findings from one study in one context will apply to other contexts (Lincoln and Guba, 1985)
	Falsification	Theory must be open to refutation through substantive evidence (Popper, 1959)	Analytical generalization	Extend to which theory developed from one case is extended to other situations with similar conditions (Yin, 2003)
Consistency *The consistency of the data*	Reliability	Extent to which a study's operations can be repeated with the same results (Yin, 2003)	Dependability	Extent to which the coherence of the internal process and the way the researcher accounts for changing conditions in the phenomena (Bradley, 1993)
			Recoverable	Extent to which the research process is completely exposed for others to critical scrutiny (Checkland and Holwell, 1998)
Neutrality *Findings are function solely of the informants and conditions of the research*	Objectivity	Use of instruments without dependence to human skills and perception (Patton, 2002)	Confirmability	Extent to which interpretation are the result of participants and the phenomenon as opposed to researcher bias (Bradley, 1993; Lincoln and Guba, 1985)
	Construct validity	Extent to which correct operational measures are established for the concept being study (Yin, 2003)		

In quantitative research, *internal validity* refers how confidently one can conclude that the observed effect(s) were produced solely by the independent variable and not extraneous ones. According to (Yin, 2003), *internal validity* is a concern of exploratory or causal cases but not for exploratory or descriptive case that do not attempt to make causal statements. In this case of qualitative study, *credibility* replaces the idea of internal validity and refers to the accuracy of the study e.g. how well the study was run. A qualitative study is credible when it presents such accurate description or interpretation of the empirical data (Sandelowski, 1986). This criterion is perhaps the most important for the assessment of qualitative research.

In quantitative research, *construct validity* refers whether the means of measurement are accurate and whether they are actually measuring what they are intended to measure. The latter idea refers to the notion of objectivity. Objectivity in science is associated with the use of instruments that are not dependant on human skills and perception (Patton, 2002). He recognized the difficulty of ensuring real objectivity and the inevitable intrusion of researcher's biases. Qualitative researchers are face to the same problem. They have to ensure that the findings are the result of the informants and hence avoid potential investigator subjectivity. For quantitative researchers have to understand multiple realities that informants have in their mind. For this reason, many authors advocated to use triangulation to improve the *construct validity* by reducing the researcher bias. For example, the use multiple sources of evidences (several informants, documentation) or the combination of qualitative and quantitative methods to collect data (McCutcheon and Meredith, 1993; Patton, 2002; Yin, 2003). Two other remedies proposed to emphasise *confirmability* are establishing a chain of evidence and having a draft case study report reviewed by key informants(Yin, 2003).

*External validity*represents the extent to which findings draw from studying one group can be generalized or applied to other groups or settings (McCutcheon and Meredith, 1993). In quantitative research, this criterion means that the results can be applied to a wider population in any situation and time frame where the assumptions hold. In field research, dependence on a single case renders incapable of providing this type of generalization. However, the results can be extended to "other group or setting not to augment the number of data points to increase the confidence within group findings" (McCutcheon and Meredith, 1993). Thus, it better to express *external validity* in terms of the generalizability of cases to theoretical propositions rather than populations. For this reason, the term *extrapolation* or *transferability* rather than generalization is more appropriate for qualitative research. The extrapolation of theory requires a logical approach by analysing similar or different factors present in the new situation, known as *analytical generalization* (Yin, 2003). In this respect, the case study is ideal for generalizing (Flyvbjerg, 2006) using the test of *falsification* introduced by (Popper, 1959). Indeed, the field research is well suited for identifying 'black swans' because of its in-depth approach.

4 HOW DO THE CRITERIA RELATE TO THE EXAMPLES?

To explore these criteria, we return to the two examples that we introduced in Table 1, making the assumption that these are research efforts have been peer reviewed and recognized as adding value to design research. Both of the research approaches are evaluated (Table 4) with respect to what is reported explicitly with each criterion presented in Table 3.

Table 4: Criteria Explicitly Addressed in Comparison Papers

	Simulation Research (NT/PS) (Papakonstantinou et al., 2012)			**Empirical Research (EM/DS I)** (Marini et al., 2011)		
	Usual criteria	**Explicit**	**How**	**Usual criteria**	**Explicit**	**How**
Truth Value	Internal validity	N	The details of the program are not provided; it is assumed that the programming is done correctly.	Credibility	N	The type of the company and product is similar to many others (mechanical systems), but the justification of the choice of the case was not made clear
Applicability	External validity Generalization	Y	Used an externally defined problem as their simulation model.	Transferability	Y	Cross case analysis showed similar findings
	Falsification	N	Single example problem used, but multiple iterations run on this problem	Analytical generalization	Y	Cross case analysis with other research reported in the literature
Consistency	Reliability	N	Computer coding was not probabilistic Model was detailed, so others can repeat the simulation with different code.	Dependability Recoverable	N	Details of the data collection were made available
Neutrality	Objectivity	Y	The model of the system is human dependent, but the simulation tool is independent (deterministic and repeatable for the same input model).	Confirmability	Y	The coding patterns are based on quantifiable data, not interpretation
	Construct validity	N	The model is not validated			

The empirical study paper (Marini et al., 2011) aligns with the ES classification and the DS-I stage, while the simulation study paper (Papakonstantinou et al., 2012) aligns with NT classification and the PS stage as described in Table 2. Further, the empirical study is recognized as qualitative research and the simulation study as quantitative. It is important to note that we are not judging the value of the research presented in these papers, merely using them as illustrations of topically similar research with different approaches.

5 DISCUSSION AND FUTURE RESEARCH DIRECTIONS

The review of quality criteria used in qualitative and quantitative research allows us to distinguish two types of criteria: verification and validation criteria. We draw inspiration from the distinction made between Verification and Validation processes (V&V process) in software and systems development (Pineda and Kilicay-Ergin, 2010; Tokmakoff et al., 1999). We propose the following definitions:

- Verification refers to the question: Are you doing the research right? Criteria relate to process
- Validation refers to the question: Are you doing the right research? Criteria relate to findings

The verification and validation related criteria are used to compare the two research methods of Table 1. In this comparison (Table 5), the validation criteria seem to be explicitly addressed in each paper, while the verification criteria are not.

Table 5: Comparison of Simulation Research and Empirical Research with Respect to Verification and Validation

		Verification criteria		
Trustworthiness dimensions	**Simulation Research** (Papakonstantinou et al., 2012)		**Empirical Research** (Marini et al., 2011)	
	Usual criteria	**Explicitly addressed**	**Usual criteria**	**Explicitly addressed**
Truth Value	Internal validity	N	Credibility	N
Consistency	Reliability	N	Dependability Recoverable	Y
Neutrality	Objectivity Construct validity	Y N	Confirmability	Y
		Validation criteria		
Applicability (generalizability)	External validity Falsification	Y Y	Transferability Analytical generalization	Y Y

In simulation research, the validation criteria are naturally addressed. Verification criteria are not explicitly addressed (except objectivity) and are certainly considered by the authors as implicit within a positivist tradition (Avenier, 2010). In the empirical case, the authors were aware that details were necessary to convince the readers of the quality of their case study but they have partially addressed the verification criterion, possibly because of limited space within a typical conference paper. Regardless of research type, we argue that authors have to be sensitive to how quality is demonstrated by explicitly providing more information to the readers regarding verification criteria evaluation.

In empirical research, the verification criteria are considered crucial to demonstrate the research quality. Many authors suggested methods of addressing this to improve verification criteria (K. M. Eisenhardt and Graebner, 2007; Meredith, 1998; Yin, 2003). For example, one might use data or researcher triangulation, establishing a chain of evidence, or doing pattern matching through cross analysis. The literature, however, is surprisingly sparse in describing to what extent verification criteria for simulation research should be operationalized. The issue of how the verification and validation criteria can be operationalized according to the method adopted is left for future research.

There is an epochal difference between many research fields. Traditional science, such as material testing, has been established as a discipline for centuries. This has resulted in standards detailing how to conduct material tests as defined by ASTM (http://www.astm.org/). Therefore, in traditional science, the verification is less important as it has already been standardized and canonically accepted by the community. Simulation has been done for decades, yielding some common/canonical benchmarking and other near standards. This means that there is some consideration given to the verification, but perhaps most of the researchers' emphasis is on the findings rather than detailing their experimental protocols. In terms of empirical research, these have been done for years. There are no standards developed for the process of doing this research in studying engineering design. Therefore, more emphasis is placed on verification of the process of conducting the research. Verification and validation are interconnected to different degrees. Nothing can be assumed valid unless the process has been verified. The interconnection is of extreme concern with empirical research and less important with traditional science and simulation work due to the standards or canonical state of the art where the common best practice is accepted.

A question remains: is this difference based on the maturity of the research field or is it based on something more central and inherent to the research methods and objectives? Some argue that design research is in its “pre-paradigm” stage and therefore verification is critical (Beitz, 1994; Eder, 1998; Horvath, 2004), but we argue that there are other considerations such as the contextualization/abstraction in the research approach itself. The intellectual silos of researchers tend to insulate them so that they might not be aware of the methods as employed in other fields. It is imperative that design researchers stretch their understanding and appreciation of research methodology to include the study of research methods in other disciplines (Reich, 2010).

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