Jun 25th, 9:00 AM

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Citation
Jian, P., Gu, J., and Olechowski, A. (2022) Connecting creative product design processes to creative product design outcomes: A scoping review, in Lockton, D., Lenzi, S., Hekkert, P., Oak, A., Sádaba, J., Lloyd, P. (eds.), *DRS2022: Bilbao*, 25 June - 3 July, Bilbao, Spain. https://doi.org/10.21606/drs.2022.657

DRS 2022
Bilbao 25th June — 3rd July

Connecting creative product design processes to creative product design outcomes: A scoping review

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doi.org/10.21606/drs.2022.657

Abstract: Generating repeatable guidelines for designing creative products has long been an aim of the design research community. Even so, a widely trusted or agreed-upon process has not yet emerged. As a first step toward this goal, it is important to take stock of the reported connections between creative design processes and creative design outcomes. Thus, we conducted a scoping review focusing on creative *product design.* Our search identified 130 papers published from 1969 to 2021. The most frequent study type was a proposal paper (n = 53). Twenty-seven of the included papers used experimental methods. When connecting the creative design process to the outcome, 72 papers theorized about how the targeted design process could influence design outcome creativity; 58 papers used empirical methods to assess outcome creativity. These findings suggest that more empirical studies are needed to examine the process-to-outcome association in creative product design.

Keywords: creative design process, creative design outcome, scoping review, product design

1. Introduction

1.1 Background

Creativity plays a significant role in the design process across various fields, promoting innovation, helping with problem-solving and increasing market share (Sarkar & Chakrabarti, 2011). A lack of creativity in designs can lead to discounted commercial value. The indispensability of creativity was emphasized in an investigation by the UK treasury in 2005 (Elmansy, 2014), in which it was shown that leading innovation-driven corporations made 75% of their income from commodities and services that did not exist 5 years previously. Companies that fail to produce creative products or services are at risk of being left out of the industry in the long term (Howard et al., 2008). As the creative design industries become more competitive, designers and research and development teams are under great pressure to develop unprecedented and ground-breaking ideas. This demand for creative designs calls for a reliable design process that can guide the designers to produce creative outcomes.

Despite the abundance of creative design process research, a widely agreed-upon process that can generate creative design outcomes has not yet been adopted. In this paper, we address this research gap through an investigation of process-to-outcome connection (P-O connection) in creative design. At least two challenges contribute to this research gap. First, when developing a creative design process, researchers must ensure the design process can operate as theorized; more advanced features, such as improving creative outcomes, are secondary concerns. In other words, a design process's validity, efficacy, and efficiency are usually validated before its connection to creative outcomes. For example, Hasegawa and colleagues proposed a design support system called the *creative and inventive design support system* (CDSS; Hasegawa et al., 2011). The CDSS supports designers in combining existing elements into novel ideas. The system consisted of two steps: problem understanding and problem-solving. Problem-solving was further broken down into three phases: solving by bottom-up thinking, contradiction solving, and solving by top-down thinking. The authors quantitatively evaluated the effectiveness of the proposed CDSS. The experiment's design task was to improve a vacuum cleaner. Seventy-two students completed the design task and answered a survey. The survey results showed that the CDSS aided the students in finding design solutions and combining ideas. However, whether the solutions and ideas were creative was not examined.

In addition to the example described above, Howard and colleagues reviewed over 40 creative design processes in engineering design and cognitive psychology and identified a need to connect the creative design process with creative design outcomes (Howard et al., 2008). The authors then proposed a model that linked "design operations" to the "nature of the activities in creative process terms" and "resultant creative design output." For example, the "formulation" process in design operations relates to "generation" in terms of the cognitive process of creative design, and they both link to an "original" creative design output. Howard and colleagues developed this model mainly based on the function, behaviour, and structure framework (FBS) of design (Gero & Kannengiesser, 2004). When reading this paper, we asked whether researchers could use this model to characterize other design processes. This question led to the second challenge contributing to the lack of P-O connection in creative design—the variety of design processes renders it difficult to evaluate the connection to creative outcomes using the same construct.

Linear design processes guide designers in a step-by-step fashion. For example, the Osborn-Parnes creative problem-solving framework divides finding creative design solutions into five stages: 1) mess-finding and objective-finding, 2) fact-finding, 3) problem-finding, 4) idea-finding, and 5) solution-finding (Parnes, 1967). The Pahl and Beitz' systematic approach describes the design process in four stages: 1) task clarification, 2) conceptual design, 3) embodiment design, and 4) detail design (Pahl et al., 2007). Nonlinear design frameworks suggest that the creative design process is iterative instead of stepwise. The theory of inventive problem solving (TRIZ) is a popular nonlinear design process. TRIZ supports creative design by facilitating creative problem-solving (Mahto, 2013). TRIZ relies on previous experience and suggests that repeated problems can be used as tools for problem-solving. The knowledge space models, such as the C-K theory (Hatchuel & Weil, 2003), formalize the creative design process as gaining and synthesizing knowledge. The divergent-convergent models formalize the cognitive process of creative design. For example, Pugh proposed the controlled convergence process (Wijnia et al., 2009), and the Design Council in the UK established the double diamond framework, which combines divergent and convergent thinking and applies them to design activities (Design Council, 2015). Each design process has a unique theoretical basis, iterative pattern, and application purpose. The diversity of the design processes offers great flexibility and versatility. However, the diversity also makes it difficult to assess the attributes of the design processes with a standardized method.

1.2 Research objective

These two challenges inspired our research. Because of the first challenge, studies have tended to prioritize assessing a design process's usability over assessing the P-O connection. As a result, when the design outcomes' creativity is assessed, the results may not be listed as the primary finding. Because of the second challenge, the methods used to evaluate the P-O connection may be inconsistent across design processes. With a scoping review, we can identify papers with results on P-O and investigate the breadth of research in methodology and types of design processes and outcomes. To address the first challenge, we will look beyond the highlighted key findings to record any commonly underreported result of design outcomes' creativity. We will also include studies that assessed metrics that can reflect creativity, even when a paper does not explicitly connect the result to creativity. For example, a paper might report that a design process is associated with more design outcomes but might not mention *creativity*. We will still include this paper because the quantity of design outcomes is a metric of creativity. To address the second challenge, we will record the targeted design process in each paper, develop coding themes that can characterize various design processes, and use visualization tools to map the included articles.

1.3 A focus on product design process

This scoping review is part of a larger research project that studies the creative design P-O connection in all design fields. Our search did not exclude any specific design fields. By being inclusive, we hope the results can highlight interdisciplinary insights, identify the design fields with more advanced design frameworks, and analyze the connection between the creative design process and various types of design outcomes.

We have chosen product design as our first step of the analysis. Our reason to start with *product design* is three-fold. First, product design is a multidisciplinary activity involving engineering design, aesthetic design, and market-need analysis. This provides us with two advantages: 1) *product design* is less likely to have a single best practice that may restrict the applicability of many design processes; 2) by reviewing *product design*, we can establish a coding protocol that is adjustable to other design fields in our next steps. Second, *product design* has a clear outcome, simplifying the evaluation of creativity. Finally, creativity is an essential feature of attractive products. In the medical field, a new drug or therapy program may rely more on efficacy than novelty. In contrast, novelty, innovation, and originality are crucial to making new products stand out in the market.

This paper aims to answer three key questions. First, to what extent has current research examined the association between the creative product design process and creative products? Second, what methodologies have been used to research this P-O connection? And finally, what are the research trends in recent years?

2. Method

2.1 Scoping review protocol

Our research team developed a scoping review protocol adapted from Tricco and colleagues (2016), which was informed by Arksey and O'Malley (2005) and the Joanna Briggs Institute scoping review manual (Peters et al., 2015; Peters et al., 2020). The protocol detailed the research objectives, inclusion and exclusion criteria, and search strategies. Our complete protocol is stored on Open Science Framework (OSF) (Jian & Olechowski, 2021). Finally, we followed the PRISMA-ScR Checklist to report on the rationale, method, results, and discussion of this review (Tricco et al., 2018).

2.2 Eligibility criteria

We included papers that both 1) discussed, proposed, tested, or improved upon a complete or part creative design process and 2) examined the creativity in the design outcomes, either theoretically or empirically. To satisfy the first criteria, the paper had to include a detailed description of the design process. To satisfy the second criteria, the authors of the paper had to either theorize how the creative design process could connect to creative outcomes or measure the design outcomes' creativity qualitatively or quantitatively. We also included papers that did not explicitly investigate connections to design outcomes' creativity but measured the design outcomes with metrics that could reflect creativity. We obtained the metrics from past widely-cited papers on ideation effectiveness (Shah et al., 2003) and creativity assessment (Oman et al., 2013). The following is a list of eligible creativity metrics:

- novelty—uncommonness of design outcomes
- quantity—number of design outcomes
- variety—number of outcome categories
- usefulness—how well the outcome meets the design task constraints

We included peer-reviewed journal articles, peer-reviewed conference articles, theses, and book chapters published after 1900. We initially included papers from all creative design fields, including but not limited to product design, architecture, fine arts, literacy, visual design. We included all study designs, including theoretical papers, qualitative studies, quantitative studies, and review papers. We also included papers that focused on a design process with practical or digital assistive tools if the papers demonstrated connections to creativity in the design outcomes.

After pilot screening 50 papers, our team reached a consensus on the following exclusion criteria for papers:

1. aimed to improve general creative reasoning without connections to the design process
2. designed by individuals under 16 years old
3. provided proof of concept for commercialized platforms
4. designed therapies to improve the creativity of clinical populations
5. optimized organizational decisions to improve creative designs

2.3 Information sources and search strategy

We searched five electronic databases: PsychInfo, Compendex, GEOCASE, GeoRef, and Inspec. Choosing these databases allowed us to include papers on the psychology of creative design, creative engineering design, and other interdisciplinary fields. A complete search strategy record is included in the review protocol (Jian & Olechowski, 2021).

2.4 Study selection process

We conducted our last search on November 16, 2021. We imported all returned items into Covidence, an online software for literature review (*Covidence Systematic Review Software, 2021*). Covidence automatically detected and removed duplicates. Two members of the research team performed study selection. In phase I, the two reviewers screened the titles and abstracts. While screening by title and abstract, the reviewers tagged each paper by its design domain. Domain tags included “product design,” “mechanical design,” “visual art design,” “musical design,” “program design,” “civil engineering,” “systems engineering,” “software engineering,” and “others.” Each paper could have more than one tag. If the two reviewers tagged a paper with different labels, the paper would have labels from both reviewers. Only papers with a “product design” tag entered phase II. In phase II, the two reviewers performed full-text screening. Non-English articles were translated with Google Translate. In phase III, the two reviewers extracted all data for coding. The two reviewers resolved all discrepancies through discussion.

2.5 *Data Items and Data Abstraction Process*

After obtaining a final list and extracting the articles, we abstracted data on study characteristics following scoping review study guidelines (Moher et al., 2011). We performed a pilot abstraction session with 20 articles to formalize the abstraction form. Essential paper characteristics were the year of publication, continent of publication, publication source (e.g., journal article, conference article, or book chapter), and language. We developed coding protocol to transfer raw data to intelligent data and stored the collected data in Excel format. We finalized the abstraction form and coding protocol with the four essential study characteristics and 19 additional themes. The following paragraphs describe the method for coding themes most relevant to the research questions. For a complete coding protocol, please see Jian and Olechowski (2021) for an online repository of the protocol document.

We recorded and coded the theme of the "design process" emphasized in each paper with open-end coding. If the paper used an established design framework, we recorded the name of the design framework. If the paper developed an original design process without a designated name, we recorded the design process as "customized." A paper could contain multiple design process. We used the Pahl and Beitz' systematic approach to tag the design process with design stages—"task clarification," "conceptual design," "embodiment design" or "detail design"—along with an additional "implementation" stage (Pahl et al., 2007).

To code creative design outcomes, the creativity metric used four coding themes: "novelty," "quantity of outcomes," "variety," and "usefulness." The creativity metric was open-ended. If the paper did not explicitly identify creativity metrics, we would analyze its creativity measurement and code it. For example, if the design process led to more radical ideas, we would code the creativity metric as "novelty." If the paper did not assess any creativity metrics, we would record the metric as "unspecified." We also coded the measurement type under five categories: "discussion," "qualitative," "quantitative," "mix-analysis," or "unspecified." The creativity assessment instrument recorded what the researchers used to obtain creativity data, such as the consensual assessment technique or designers' self-report. Finally, we recorded the creativity result valence as "positive," "negative," "neutral" or "other." If the examined design process was associated with better creativity in design outcomes, the creativity result valence would be coded as positive. If the association was negative, the coding would be negative. If the design process's effect was overall neutral or if the process had both positive and negative effects, the valence would be "neutral." For papers that did not report the valence of the results and those that compared multiple processes, the result was coded as "other." Papers that did not empirically assess creativity might still discuss how a proposed process might influence a creative outcome. Such a discussion could also have a creative result valence.

For example, Vitalletti et al. (2019) reported a case study of using genetic algorithms (GA) to support the co-creation design of lamps. Designers collaborated with customers and used GA to select ideas, like how evolution selects certain traits. The authors did not empirically measure the creativity of the final product, but they discussed a relevant risk to their design approach. The authors pointed out that GA might be better for designing outcomes that suit the public instead of supporting creative designs with unique and distinct features. In this case, the creativity metric was "novelty," the measurement type was "discussion," and the creativity result valence was "negative."

To capture critical research trends, we recorded additional coding themes, presented in Table 1. See OSF repository for a complete coding protocol (Jian & Olechowski, 2021).

Table 1. Coding Protocol for Other Coding Themes.

Theme	Description	Coding Options
Assistive Tool	External tools that design process integrated	CAD; Algorithm; Cues; Interactives (AR/VR); Databases; Other
Study Research Method	Type of paper based on research method	Discussion Paper; Review Article; Empirical Study; Case Study; Proposal; Other
Design Environment	Design environment that hosted the design task	Course Project; Industrial Project; Competition; Workshop; Event; Laboratory Study; Unspecified
Design Expertise	Level of experience of the designers who operated the design process	Novice; Expert; Unspecified; Both
Design Inspiration	External sources from which designer received inspirations	Open-ended coding. Examples include Co-Create; Social Network Platform; Culture; Analogy; Biomimicry; Sustainability
Design Outcome	Outcome of the described design process	Idea/Concept; Digital/Sketch Model; Prototype; Product; Unspecified
Collaboration Mode	Whether the design process was cooperative	Individual Work; Teamwork; Unspecified

3. Results

3.1 Literature search results

We summarized the literature search results using the PRISMA systematic review flowchart (see Figure 1; Page et al., 2021). From five databases, we obtained 4,348 papers. Covidence automatically removed 1,217 duplicated papers. Phase I screening by abstract and title excluded 1,678 papers. Five hundred fifty-four papers were tagged with “product design” and entered phase II, full-text review. Because our search did not limit geographic location or language, we failed to find the full text of a large number of papers (n = 134). Eventually, 130 papers were eligible to enter our final analysis.

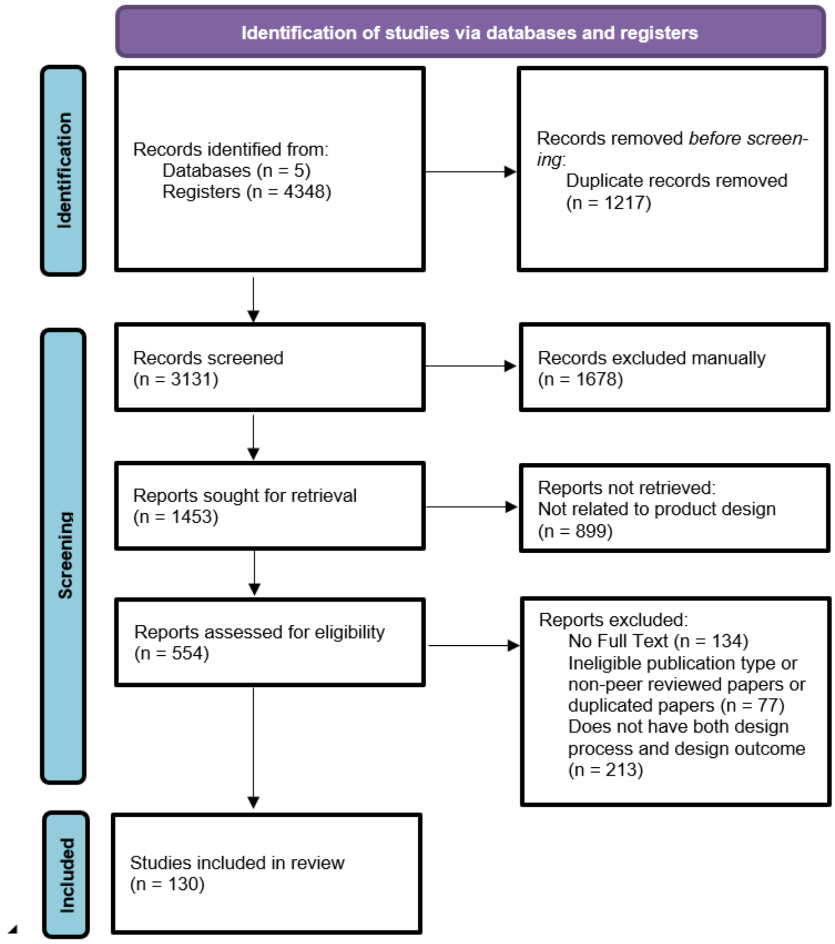

Figure 1. With this flowchart, we recorded the number of papers entered and excluded from each data screening and selection phase.

3.2 Study characteristics

In Table 2, we summarize the articles by continent, publication type, and language: 45% of the research was conducted in Asia (n = 59), and another 32% in Europe (including the UK; n = 41); 70% of the articles were published in academic journals (n = 91) and 27% as conference articles.

Table 2. Study Characteristics.

Characteristics	**Value**	**Count (%)**
Continent	Asia	59 (45.4%)
	Europe (including UK)	41 (31.5%)
	North America	16 (12.3%)
	Multiple continents	9 (6.9%)
	Central and South America	2 (1.5%)
	Africa	2 (1.5%)

	Australia and New Zealand	1 (0.8%)
Publication type	Journal article	91(70.0%)
	Conference article	35 (26.9%)
	Book (including book chapters)	3 (2.3%)
	Thesis	1 (0.8%)
Language	English	123 (94.6%)
	Chinese	5 (3.9%)
	Japanese	2 (1.5%)

In Figure 2, we visualized the number of papers in our review per 5-year interval. We observed a sudden spike in the amount of research at years 2006–2010, indicating that research on product design's process-to-product connection is a relatively young field with 15–20 years of extensive research.

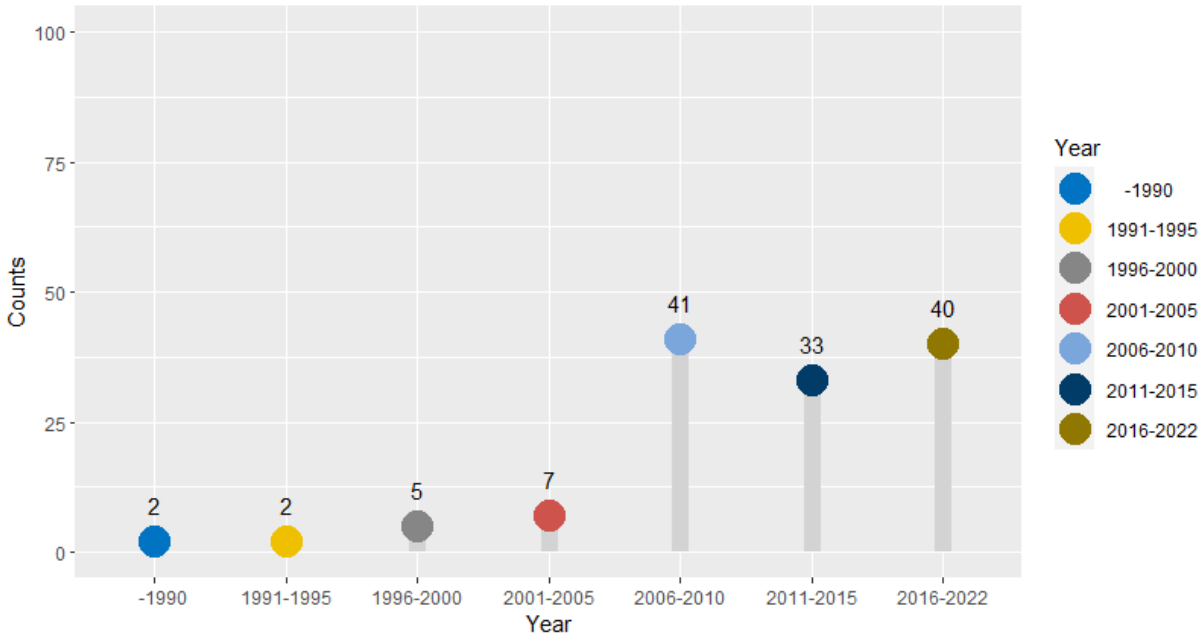

Figure 2. The x-axis is publication years divided into seven bins; the y-axis is the number of papers published within each year range.

Our main research objective was to map the literature that connects design processes and creative design outcomes. First, we analyzed the research methodology used in the field. Because *Research Method* has more than four categories, we used a donut chart to visualize the frequency of different types of studies (see Figure 3). Studies that proposed a design process are most common (n = 53, 40.8%). Experimental studies (n = 27, 20.8%), discussion papers (n = 24, 18.5%), and case studies (n = 22, 16.9%) take up similar proportions. The least frequent study design is review papers (n = 4, 3.1%).

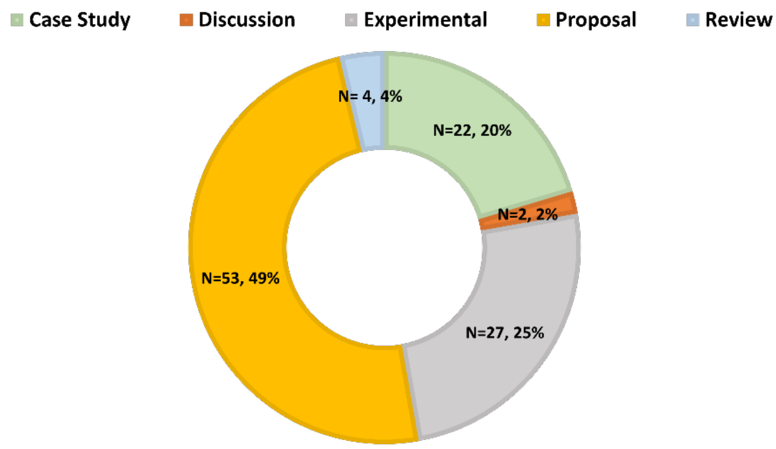

Figure 3. This donut chart visualizes the frequency of papers' research method types. The larger the coloured area, the more frequent the category.

3.3 Design processes

We mapped the papers to design stages. Fifty-five papers targeted all design stages as a whole, and nine papers did not specify the design stages. A paper can have multiple sub-stage tags. Fifty-eight papers examined the conceptual design stage, one paper examined embodiment design, and two papers were about detail design. No paper studied the implementation stage (see Figure 4).

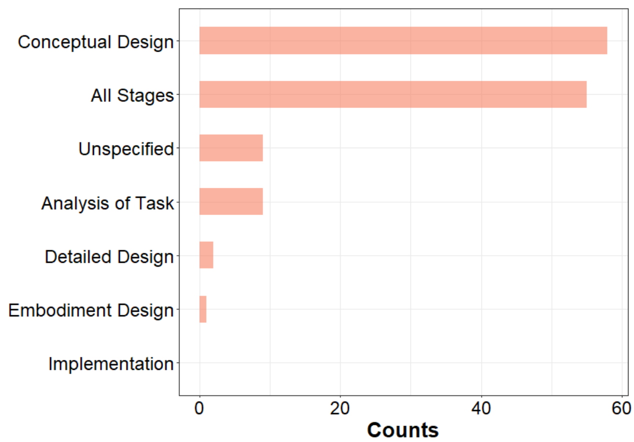

Figure 4. This bar plot visualizes the frequency distribution of design stages in each paper; note that a paper might specify more than one design stage; the x-axis is the total number of papers examining each design stage.

Next, we synthesized the design processes in each paper. Fifty-two papers used customized design processes with no designated name; 78 papers used established design processes. We found a total of 66 unique design processes; 56 of the 66 processes were used by only one paper. Here, we synthesize the design processes presented in multiple articles (Table 3). The most popular design processes are TRIZ (n = 6), meta design processes (n = 5; processes that help designers choose a design process), case-based reasoning (n = 4), heuristic-based designs (n = 4), brainstorming (n = 4), unspecified iterative design processes (n = 3), FBS models (n = 2), functional analyses (n = 2), Pahl and Beitz's systematic approach (n = 2), and product development processes (PDP; n = 2). Seven studies targeted more than one design process. We categorized these studies based on their research purpose: to compare, describe, or integrate multiple processes (see Table 4). Three papers integrated multiple design processes; three papers described multiple design processes; only one paper compared different design processes.

Table 3. Creative design processes examined by multiple papers, ranked by frequency.

Design Process Name	Papers built on this design process (no.)	Percentage of papers with noncustomized design processes	Percentage in all included papers
TRIZ	6	7.8%	4.5%
Meta Design Process	5	6.5%	3.8%
Case-Based Reasoning	4	5.2%	3.0%
Heuristic-Based Design	4	5.2%	3.0%
Brainstorming	4	5.2%	3.0%
Iterative Design Process	3	3.9%	2.3%
Function, Behaviour, and Structure (FBS) Model	2	2.6%	1.5%
Functional Analysis	2	2.6%	1.5%
Phal and Beitz's Systematic Approach	2	2.6%	1.5%
Product Development Process (PDP)	2	2.6%	1.5%

Table 4. Papers examining multiple creative design processes, ranked by author name.

Paper Citation	Design Process Names	Purpose
(Chulvi et al., 2012)	Brainstorming, functional analysis and SCAMPE	Compare
(He & Feng, 2013)	FBS and function-effect-solution (FES)	Integrate
(Huang et al., 2017)	TRIZ and TOC	Describe
(Mayda & Börklü, 2014)	TRIZ and Pahl and Beitz's systematic approach	Integrate

(Valentine, 2012)	Pahl and Beitz's systematic approach and Osborne-Parnes five-stage creative process	Describe
(Bourgeois-Bougrine et al., 2017)	Mind mapping, reverse brainstorming, TRIZ, FAST, SADT, APTE, and IRAD	Integrate
(Wachs, 2018)	Brainstorming and functional analysis	Describe

3.4 Design outcomes

Next, we reviewed what the papers examined as the design outcomes and how they performed the analysis (Figure 5). Of the included papers 36.2% (n = 47) examined the creativity of ideas or concepts as the design outcome, and 25.4% used final products as the outcome (n = 33). Digital models are next, taking up 19.2% (n = 25). Last, 2.4% examined creative prototypes (n = 7).

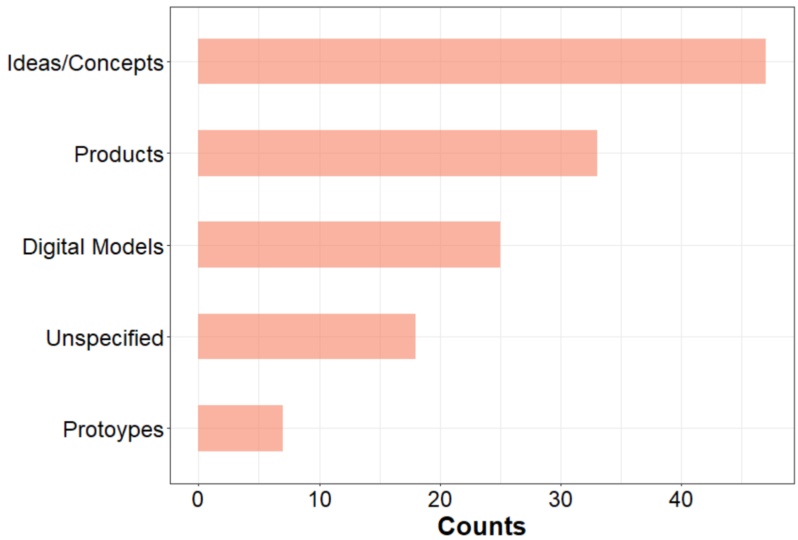

Figure 5. This bar plot visualizes the frequency distribution of the design outcomes in each paper; from top to bottom the outcomes are ranked by frequency.

We then recorded how each paper examined the association between the creative design process and creative design outcome (Figure 6). Most of the papers discussed the potential of such an association (n = 72, 55.4%); 23.1% of the papers used quantitative assessment (n = 30); 16.1% used qualitative assessment (n = 21); and seven studies used a mix of quantitative and qualitative assessment (5.4%).

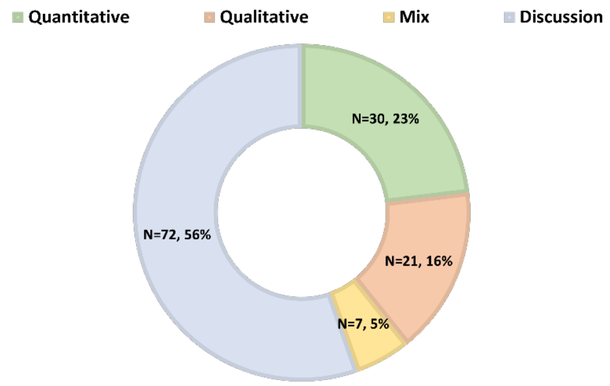

Figure 6. Because creativity measurement type has four categories, the data are presented in a donut chart; the larger the coloured area, the more frequent the category.

To obtain more insights into the creativity measurement of design outcomes, we plotted the number of papers using different measurement methods (quantitative, qualitative, mix, and discussion) by types of creativity outcome (Figure 7). We see that, for digital models, full products, prototypes, and unspecified design outcomes, papers tended to discuss how the product design process could affect the creativity of the design outcome without qualitative or quantitative measurement. For ideas or concepts, more papers used the quantitative method to assess the of design outcome creativity. These results suggest that in product design research, quantitative tools for measuring *design concepts* are more mature and accessible than quantitative or qualitative tools for measuring other design outcomes.

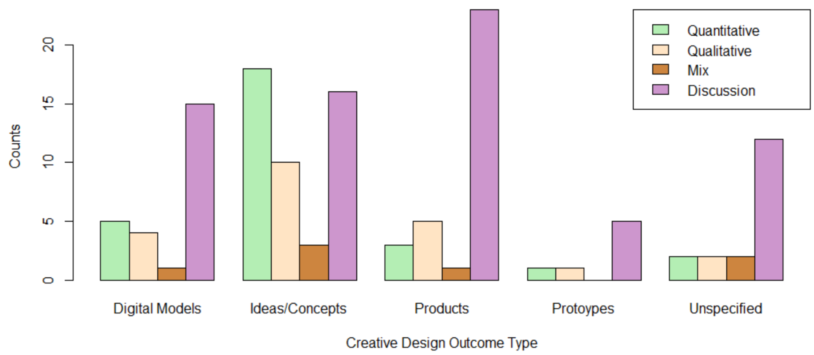

Figure 7. The x-axis is different types of creative design outcomes; the y-axis is the total number of papers. Four bars are plotted to represent the number of papers that used different measurements to assess the creativity of design products.

We also coded the instruments used to assess the creativity of design outcomes. We found 10 unique qualitative instruments and 16 quantitative instruments. Here, we report the most frequent instruments (Table 5). For qualitative methods, eight papers used a designer evaluation questionnaire, and six interviewed experts for their opinions on the creativity of the design outcome. Three papers relied on designers' self-reports, and three papers used researchers' subjective observations. For quantitative methods, nine papers counted the number of creative outcomes; eight papers used customized rating scales operated by the researchers; six papers used expert ratings, and four papers used consensual assessment technique (CAT), an established creativity assessment method using expert ratings. For a complete list, please access our OSF repository (Jian & Olechowski, 2021).

Table 5 Creativity Assessment Methods and Instruments, Ranked by Frequency.

Creativity Measurement	Measurement Instrument	Number of papers
Qualitative	Designer evaluation	8
	Expert interview	6
	Designer self-report	3
	Researcher observation	3
	Protocol analysis	1
	Similarity analysis	1
Quantitative	Counting	9
	Researcher coding/rating	8
	Expert rating	6
	Consensual assessment technique (CAT)	4

Papers in our review included a variety of metrics to reflect creativity. Other than 35 papers that did not specify creative metrics, we found 21 unique metrics, including unspecified (n = 35), novelty (n = 65), quantity (n = 16), variety (n = 14), originality (n = 13), usefulness (n = 8), level of innovation (n = 3), quality (n = 2), comprehensiveness (n = 1), effectiveness (n = 1), systematic level (n = 1), efficiency (n = 1), individuality (n = 1), feasibility (n = 2), safety (n = 1), resolution (n = 1), unobviousness (n = 2), specific targeting (n = 1), appropriateness（n = 3), uniqueness (n = 1), and presentation of additional elements (n = 1).

3.5 Trends in creative design research

We conducted exploratory analyses that revealed interesting trends in creative product design research. First, we analyzed the assistive tools supporting creative design. From Figure 8, we observed a holistic trend showing that recent research on creative engineering design contains more diverse design assistive tools. Computer-aided design (CAD) received more attention from 2006 to 2011, and its popularity persists till today. Researchers have studied creative design processes that involve databases and interactives (AR and VR) more recently. Others include cocreative platforms, assistive design tools, or models such as the 5 Rs of sensational thinking (O'Neill & Shallcross, 1994) and design philosophies.

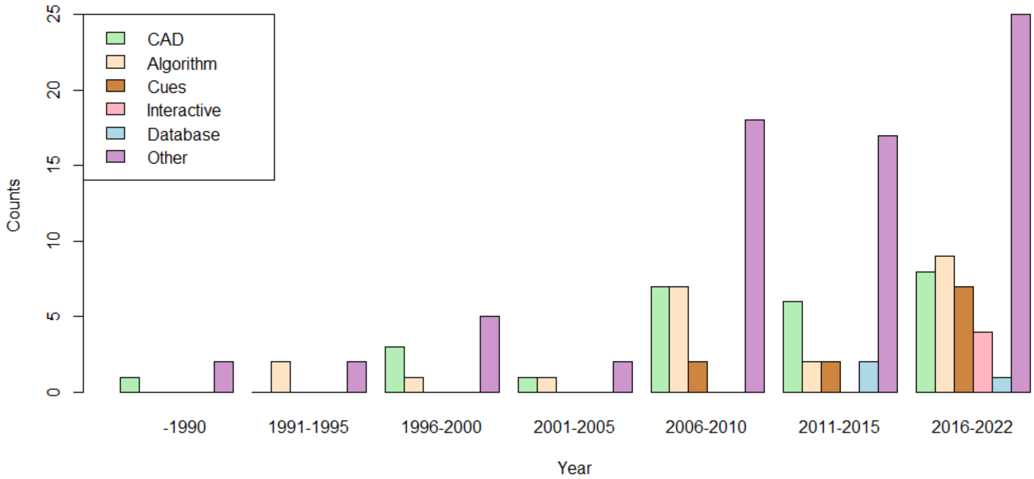

Figure 8. The x-axis is year of publication divided into seven bins; the y-axis is the number of papers; six bars represent different assistive design tools integrated in the design process.

We also analyzed trends in design inspirations. Cocreation, where designers interact with customers during the design process, is a popular topic; sustainability and culture have also received more attention in the past 10 years (Table 6).

Table 6 Design Inspirations, Ranked by Frequency

Design Inspiration	**Papers Citation**	**Number of Papers**
Co-create	(Ali & Liem, 2015); (Campbell & Beer, 2008); (Frow et al., 2015); (Karimi, 2019); (Lee & Chang, 2010); (Masclet et al., 2021); (Pniewska et al., 2013); (Vitaletti et al., 2019); (Wu et al., 2010);	9
Sustainability	(Acharya et al., 2019); (Cucuzzella, 2016); (Doelling & Nasrollahi, 2013); (Faludi, 2015);	4
Culture	(Yang et al., 2019); (Y.-C. Huang et al., 2018); (Zhao, 2021)	3
Bioinspired	(Forniés & Muro, 2012); (Yamada et al., 2017);	2
Empathy	(Grashiller et al., 2017); (Johnson et al., 2014)	2

4. Discussions

From the statistics on the basic study characteristics, we learned that the included papers came from an incredibly globalized research community. On the one hand, this greatly improves the reliability and generalizability of design process research. On the other hand, papers from different continents are also subconsciously or directly influenced by various cultures, making it difficult to generalize the findings. We also discuss culturally specific design processes in section 3.5, Trends in Creative Design Research. With the most common study type consisting of proposals, it is reasonable to conclude that more studies put forward new design processes than empirically examine those that are already established designs. We corroborated this conclusion in our analysis below on the design processes targeted in each article.

Our analysis of the design process and outcome characteristics showed that the field of product design had witnessed excessive new design process proposals and discussions with insufficient efforts to validate the processes in their ability to produce creative outcomes. Moreover, the diversity of the design process is more complex than its quantity—various design processes also focused on different design stages. The types of creative outcomes, creativity metrics, and measurement instruments are inconsistent. We also recorded the expertise of the designers, the design task environment, and the design collaboration mode. Because of space constraints, these results are not reported, but they can be accessed via OSF (Jian & Olechowski, 2021).

So far, we have discovered that the literature consists of various design processes, design stages, design outcomes, and outcome creativity measurements. These diversities make evaluating the process-to-outcome connection even more difficult than we assumed. We suggest that future research start with empirically testing and synthesizing design processes on the conceptual design. As Howard and colleagues (2008) stated, “Research must be conducted at lower levels of granularity to understand what detailed mechanism lead to original and appropriate ideas being produced during the generation phases” (Howard et al., 2008). The creative outcomes of the conceptual design stage are usually ideas, sketches, or digital models. Ideally, creativity should be measured with more than one instrument because different approaches might be assessing different constructs (Miller et al., 2020). After creating a reliable conceptual design process, we can move on to embodiment design, detail design, and the corresponding design outcomes.

Revealed research trends showed that the creative design process is becoming more interactive with new technologies as it receives inspiration from various sources. At the same time, researchers should be aware of the negative influence of unique design processes, especially those that utilize new technologies and algorithms. We recorded the creativity results valence; only four papers suggested a negative association between the proposed design process and the creativity of the design product. Two of these four papers used a genetic algorithm (Shahin, 2008; Vitaletti et al., 2019); one used social media analysis tools (Han et al., 2020); and one used mobile phones as a design cue (Hettithanthri & Hansen, 2020). To generate creative design outcomes, design processes must be compatible so they can include these variables and remain reliable for guiding designers to produce more creative products.

We would also like to voice a more significant concern stemming from our results. There is a significant gap in research between the introduction of a new assistive tool of creative design and the validation of a design process integrating the tool, especially in terms of the design process's connection to creative outcomes. There are significantly more proposals combined with discussion papers than empirical papers. Moreover, creative design with CAD has received more attention since the early 2000s. However, until recently, when AR and VR were applied as design tools, no widely trusted creative design process with CAD had been established and well-supported in its ability to make creative designs. Comparable to using technology readiness level to assess new technology (Olechowski et al., 2020), the grander goal in design research should also include developing a readiness scale for design processes and design tools to make sure the new design methods will not hinder the designers' creativity.

5. Limitations

In this scoping review, we attempted to establish a connection between a creative design process and creative design outcomes by including papers that examined both. However, the simultaneous presence in the same paper is not sufficient to establish a relationship between the two. In other words, just because a paper reflects the study of a creative design process and includes a measurement of the creativity of the design outcome does not mean the creative design process is correlated or associated with a creative design outcome. To establish a relationship between the two, empirical studies must be conducted to show that the creative design process can explain variances in creative design outcomes. We found 27 papers with experimental methodology, and only one compared different design processes. Because it is out of the scope of a review to assess and synthesize the study results, we suggest a focused review of the experimental papers to gain insights into the relationship between creative design processes and creative design outcomes.

Our search strategies used "creative design process" as the keywords. We tested other search words such as "design framework," but we eliminated them because of the irrelevance of the resulting papers. More comprehensive reviews in the future can include key terms such as "design framework," "design method," or "design approach." We derived the final organization of the studies' characteristics, such as *Design Stage* and *Creativity Assessment Instrument*, from existing literature and our internal discussion—we did not validate the typology. In the papers we did not use a unified measurement of creativity. Different assessment approaches and the raters' expertise can influence the creative results.

Also, we have reported here what we deemed the most impactful and meaningful data, but research teams with different foci might benefit from other analyses. A complete list of the papers we included is accessible on OSF (Jian & Olechowski, 2021).

6. Conclusions

In our study we aimed to provide an overview of existing research that connects the creative design process to creative design outcomes. Our key findings are summarized below.

- A total of 130 papers identified an association between creative design processes and creative design outcomes.
- Only 20.8% of the papers incorporated experimental methods to examine the association.
- The assessment of product creativity is inconsistent across studies, making it challenging to synthesize and validate the results.
- Product design processes have recently incorporated more computer-based tools and other digital technologies. Design processes using new assistive tools should be tested on their ability to generate creative results.
- Significantly more studies have proposed new creative design processes than papers examining established processes in their ability to generate creative products.

Given the above findings, we would like to suggest two research directions. First, there is a strong need to examine if digital assistive tools can be integrated with design processes to produce creative products. Second, developing a standardized protocol to report new design process proposals will greatly assist in designing research communication, unifying typology, and assessing the creative design processes.

In this paper we focused on product design as a starting point. Having validated our review approach, our next step is to investigate other design fields using our search results. We suspect that these new design fields are likely to have different requirements concerning the creativity of design outcomes. For example, in the medical field, a new drug or therapy program might rely more on efficacy than on novelty, but to achieve useful design outcomes, creative design processes are still necessary. As we extend our research to other design fields, more complex questions will emerge. Should creative design theories have global applications to all design fields? Is the goal of creative design to produce a creative product? Is the goal of creative problem solving to produce creative solutions? Is the ability to perform a creative design process different from the ability to make a creative product? Is the creative design process necessary for making creative products? These questions can be answered through interdisciplinary investigations that compare creative design across multiple fields.

Overall, the results of this study aim to support the development of creative design processes that have a clear, positive relationship with creative design outcomes. In this study we identified key themes of the literature, providing language to synthesize research on the process-to-outcome connection in creative design.

Acknowledgements: This work is supported by funding from the University of Toronto Dean’s Spark Professorship.

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