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Orienting Through the Variety of Novelty Metrics

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Assessing creativity of generated ideas is of crucial importance for both design research and early detection of potential innovations. By the identification of the most acknowledged novelty metrics used for creativity-related assessments in the field of engineering design, this paper aims at providing crucial information to orient through the variety of alternatives. A systematic literature review is performed by relying on the Scopus search engine, and a search strategy based on both practical and quality-related screening procedures. The work is focused on the engineering design literature, and the identified contributions are classified in terms of both creativity and novelty concepts. A set of 140 papers has been reviewed, where a subset of 37 mentioned or proposed novelty metrics has been considered. The metrics have been mapped in terms of creativity types, novelty concepts and metric types. Although it is possible to find comprehensive reviews about creativity concepts and related metrics, contributions focused on novelty metrics are currently lacking. This is the first contribution that focuses on a wide set of novelty concepts and related metrics, by mapping them to support metric selection.

Keywords
Creativity, Novelty, Innovation, Creativity assessment, Novelty assessment, Originality, Newness, Uncommonness, Unusualness, Unexpectedness.

1. Introduction

Although the words “innovation” and “creativity” are sometimes used as buzzwords in many research works [37], they are actually the lighthouse for both academics and practitioners involved in the design and development of products. Accordingly, being innovative is acknowledged to be fundamental to reach long-term economic success [31, 66], and “creative ideas” are often considered as the starting point for Innovation [6]. In other words, creative design can be used to innovate and then to improve the quality of real life [12, 17, 57]. Therefore, although Creativity is not equivalent to Innovation, it is possible to assert that they are integrated in the same complex process [64]. Indeed, there is a fundamental difference between Creativity and Innovation, because the creativity of design outcomes can be assessed or judged regardless of their implementation status [45]. Differently, in order to become an innovation, any new idea needs to be successfully spread into the marketplace [28, 33].

Assessing creativity and innovation is deemed of crucial importance for both academia and industry, but there is a plethora of available definitions for both the terms, with a consequent high variety of assessment approaches. For instance, Creativity has been defined as the ability to generate ideas that are novel, useful, and appropriate [5], but also as the ability to find solutions that are both novel and valuable [55]. Anyhow, none of the available definitions is currently accepted as universally valid [20]. Similarly, also for the term "Innovation", it is possible to find many definitions (quoting [60]), where the concept of "usefulness" is one of the most recurring one, and which can be actually used to discern innovative ideas from creative ideas. For instance, Innovation has been defined as the ability to generate novel and useful concepts [66], or the ability to produce original and useful [52] as well as novel and appropriate [18] ideas, or novel and valuable ideas [75].

Nevertheless, it is possible to observe a common parameter that swivels around them, i.e. that of "novelty" [67]. Indeed, both creative and innovative ideas and/or products are required to be "novel". Therefore, to assess both creativity and innovation of products, it is fundamental to comprehensively assess the related novelty. Unfortunately, even if focusing only on the latter parameter, it is possible to find that many different concepts of novelty are available in literature, and many different metrics are available as well. For instance, in the set of metrics proposed by [70] novelty can be assessed in two different ways. More specifically, it can be assessed by considering the set of ideas generated in a design session, each of them analysed in terms of the solutions used to implement the most characterizing functions and/or attributes. Then, the novelty score is a direct consequence of the rarity of these solutions, and the importance levels that the evaluators assigned to each attribute. The other approach proposed by [70], instead, considers a reference universe of products in order to assess the novelty of the designed ideas. These two concepts of novelty (respectively the a-posteriori and the a-priori approaches) embodies the two concepts of creativity mentioned by [8], i.e. that of Psychological Creativity (for the a-posteriori approach), and that of Historical Creativity (for the a-priori approach). The first (hereinafter called "P-Creative") approach is focused in assessing the novelty of ideas by referring to the knowledge of the designers involved in the design session. Differently, the second approach (hereinafter called "H-Creative") is focused on assessing the actual novelty, in relation to an external reference (which should represent the knowledge of the entire human race). The possible classification of novelty among "historical" and "psychological" has been already considered in literature [72].

In industrial design or architectural design applications it is possible to find a preferred type of creativity assessment (e.g. the subjective assessment performed by experts in the specific field of the assessed product type [35]). Differently, in the last two decades, many different assessment approaches have been proposed for engineering applications, where the concept of novelty has been often isolated and assessed separately.
More specifically, although the contribution described by [70] is one of the most cited when referring to novelty assessments in engineering design, many other metrics have been proposed in literature. Therefore, it can be very difficult to orient through the different concepts of novelty and the related metrics. Indeed, except for reviews focused only on a specific type of metrics [24, 27], a comprehensive review is missing, which encompasses both the P-Creative and the H-Creative metrics.

Here arises the aim of this work, i.e. to perform a systematic literature review of the metrics used in the engineering design field in order to assess novelty.

The objective of the performed review is to clearly identify the most acknowledged metrics (according to the number of received citations), and to classify them in terms of the underpinning creativity concept (i.e. P-Creative vs H-Creative), novelty concept and metric type.
This classification is deemed of fundamental importance to support both scholars and practitioners in the identification of the most suitable novelty metric, according to their specific research and/or experimental needs.

2. Research method: Systematic Literature Review

According to [22], a literature review can be a valuable research item only if performed systematically, i.e. by explicitly referring to a reproducible method for identifying, evaluating, and synthesizing the existing body knowledge. In order to meet these requirements, checklists and procedures are available in literature (e.g. [22, 59]), which can resumed in the seven points listed below:

1. Clearly define the purpose of the review, e.g. by selecting effective research questions.
2. Identification of the literature database.
3. Searching for the literature by identifying a comprehensive list of search terms and formulating effective search queries.
4. Definition and application of practical screening criteria, in order to rapidly skim undesired contributions.
5. Definition and application of a comprehensive and effective quality appraisal criteria in order to exclude low-quality and unreliable contributions.
6. Performing the review by referring to a repeatable protocol.
7. Synthesis of the results according to the research objectives.

2.1. SLR requirements 1-2

As mentioned in Section 1, the purpose of the work (Point 1) is to shed light among the different novelty metrics available in the engineering design literature. This is in line with the usual objectives that are attributed to literature reviews. Indeed, reviews are often expected to analyze the progress of a specific stream of research [2, 3, 63, 82], which in this case is focused on novelty assessment in engineering design. Additionally, this kind of research work is also expected to make recommendations [82], which in this case are expected to be comprehensively formulated in the Discussion section.

Concerning the second point of the list, the research has been performed by relying on the literature database of Scopus [21], where most of the valuable journals and conferences are indexed. The data directly available from SCOPUS (title, abstract and keywords) have been considered the starting point for the research, (performed through titles, keywords and abstracts), while the whole documents (when needed) have been retrieved directly on the specific journals or conferences websites.

2.2. SLR requirements 3-5

A single researcher performed the search activity (Point 3 of the list). The identification of the set of search terms and queries has been quite complex, because it was not possible to directly insert the term "novelty" in the Scopus search engine. Indeed, with this specific term, most of the search results were related to "novelty detection" disciplines that have purposes extremely different from that of design creativity (e.g. [53, 68]). This problem is even worse when the search space is limited to the engineering field. Therefore, a specific search strategy has been conceived. More specifically, it relies on two different search queries, to be inserted in the Scopus search engine (only English written papers are considered):

- Search query 1: TITLE-ABS-KEY (creativity OR (idea PRE/1 generation)) AND TITLE-ABS-KEY(design)) AND (LIMIT-TO(SUBJAREA, "ENGI"))
- Search query 2: (TITLE-ABS-KEY(creativity OR (idea PRE/1 generation)) AND TITLE-ABS-KEY (design)) AND (TITLE-ABS-KEY (assessment) OR TITLE-ABS-KEY (metric)

The first search query (SQ1) is focused on the identification of the contributions within the engineering field, which present the terms "creativity" or "idea generation" in the fields "title", "abstract" or "keywords". This is the most inclusive of the two search queries, and it is expected to identify the most cited contributions (limiting to the top 100 ones). However, due to the imposed limit of 100 contributions, it is not possible to ensure the presence of those articles that, although less cited, are acknowledged as important by the scientific community. To overcome this problem, the second search query (SQ2) is intentionally more restrictive, because further limits the search space to those articles presenting the terms "assessment" or "metric" in the fields "title", "abstract" or "keywords". This additional search strategy, ensures that also newer articles can be included in the review.

The results obtained with SQ1 have been filtered by checking the titles and the abstracts in order to verify whether each article was inherent with the design creativity field (Figure 1). This screening procedure is intended to perform the practical screening required for a SLR. Differently, the imposed limit to the top 100 cited contributions, is considered here as a sufficient strategy for ensuring the required quality level of the articles (thus implementing the quality appraisal requirement).

For SQ2, a more complex selection strategy has been performed, which allowed to consider newer contributions with a time-increasing citation constraint. More in particular, the quality screen performed for the second query considers publications that satisfy one of the conditions expressed in Equation 1:

$$C > Y \text{ "OR" published in 2020} \quad (1)$$

where C is the number of citations and Y is the number of years after publication.

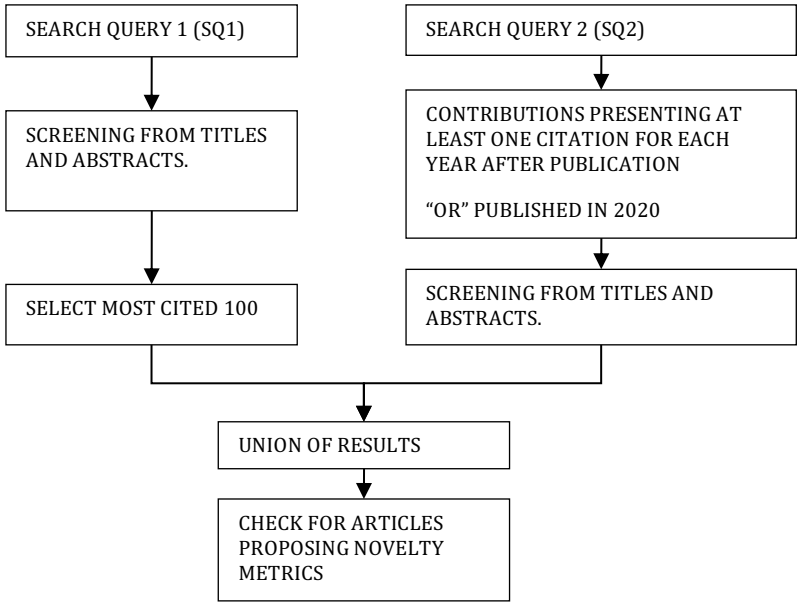

Figure 1. Search strategy with the two search queries.

Also for SQ2, an additional screening has been performed by checking the titles and the abstracts, then excluding articles not strictly related to the design creativity field. This strategy is considered suitable for the scope of the paper, since the related aim is to extract a thorough state of the art of both novelty concepts and metrics.

The citation-based rules applied for both the practical screening strategies ensured a certain quality level. Indeed, citations can be a first index about the quality of the research. Actually, some scholar assert that citations can reflect aspects related to scientific impact and relevance [1], while other assert that citations can indicate only the rigor but not the relevance, with differences between different disciplines [54]. Additionally, other scholars report that it should be necessary to distinguish between short term and long term citations to better understand the actual impact of the research [48]. Comprehensive analysis of the actual correlation between the citations and quality of reviewed research falls out of the scope of this work. Indeed, citations are considered here only to identify important contributions in literature databases [36], and to reduce the research space (e.g. [13] [29][76]).

2.3. SLR requirements 6-7

Concerning the review protocol (Point 6), it has been formulated according to the search strategy shown in Figure 1, and can be resumed as it follows:

- Retrieve information for articles identified by SQ1.
- Rank articles in terms of number of received citations.
- Perform a screening (title + abstract) to exclude non-pertinent documents.
- Stop when the number of articles that passed the screening is equal to 100.
- Retrieve titles and abstracts according SQ2.
- List the retrieved information in a spreadsheet, reporting also the publication date and the numbers of received citations for each reviewed contributions.
- Apply Equation 1 in order to discard the contributions that do not accomplish the requested conditions.
- Perform a "union" of the results coming from the two search queries.
- Check articles in order to identify which of them proposes at least a new novelty metric.
- Check articles in order to identify those that only mention or simply apply acknowledged metrics.
- Analyze the metrics in order to establish if they belong to the P-Creative or to the H-Creative families.
- Analyze the articles in terms of the considered novelty concepts.
- Check if the metric is based on the application of equations, or if it is a mere assignation of values according to predefined scales.

According to the protocol, after the union of the search results, an additional check is performed (see Figure 1) in order to identify those papers that actually propose a novelty metric. More in particular, to extract a comprehensive set of information, the articles identified by the practical screening procedure have been furtherly analyzed to exclude those missing any comprehensive contribution about novelty metrics. To that purpose, the authors of this paper independently checked the set of full-text documents and tagged them with the terms "proposing" and "mentioning" in order to discern those articles that propose new metrics from those that only mention them. In this way, it was possible to highlight the papers that propose novelty metrics relevant for the objective of this work.

Then, each of the selected articles is analyzed in terms of creativity type (P-Creative vs H-Creative) and novelty concepts (e.g. "uncommonness", "originality", "unusualness").

Eventually, the last point of the list (Point 7) requires that results are efficiently synthetized in a clear and concise form. To that purpose, the following section has been edited in order to accomplish this SLR requirement.

3. Results

3.1. Search results

The mere application of SQ1 to the Scopus search engine led to a set of 4079 documents (at February 2020), which obviously could not be processed in their entirety. Therefore, a first subset of 200 documents was taken into consideration, and the related data was downloaded (i.e. title, abstract, publication date, number of citation and DOI code).

The application of the screening procedure led to the identification of 17 non-pertinent articles in the first 117 reviewed sets of titles and abstracts. Therefore, according to the strategy described in Section 2 (see Figure 1), the process stopped, thus leading to the identification of the "Top 100 cited pertinent documents". For instance, non-pertinent documents were focused on the aesthetic of websites [46], or from very different application fields (e.g. [38, 51]).

Differently, the mere application of SQ2 led to 530 documents, reduced to 107 after the application of the rule expressed in Equation 1. Then, the application of the screening procedure excluded non-pertinent results (18 in total), thus leading to a set of 89 documents.

The application of the two search queries sometimes led to overlapping results, but also allowed to include relevant results, which would be excluded with the application of a single query. For instance, Table 1 reports the top 5 cited articles obtained with the singular application of the two search queries, highlighting that except for the article of [70], the two lists are completely different. In particular, SQ1 allowed to include the well-known contribution of [43], which were not identified with SQ2. Indeed, SQ2 explicitly referred to "metric" or "assessment", while the article of [43] was focused on "Design Fixation", but applied for the first time a specific "idea infrequency" metric that is well acknowledged in literature [25, 50].

Table 1. Top 5 (in terms of received citations) articles found with the two search queries (data retrieved on February 2020).

Rank	Articles found with SQ1	Articles found with SQ2
1	[16]	[70]
2	[43]	[69]
3	[70]	[66]
4	[47]	[50]
5	[65]	[62]

Differently, the single application of SQ1 excluded newer (and then less cited) documents, that instead, have been identified through SQ2 (e.g. [4, 15, 34]).

Then, the union of the two sets of data led to an overall set of 140 articles, whose full-text documents have been retrieved in order to perform the required analysis. In particular, it was possible to identify those contributions that actually proposed novelty metrics, thus drastically reducing the set of documents (see Figure 2). More specifically, articles excluded with the latter logic, although valuable scientific contributions, did not presented new metrics, but only mentioned or applied already existing metrics (e.g. [9, 12, 30, 40, 65]). Therefore, a further selection has been made among the latter articles, in order to identify the novelty metrics mentioned or used in the other papers, which differ from those of the previously selected 16 articles. This further analysis led to four additional metrics [7, 10, 23, 56]. In particular, within the set of the retrieved 140 articles, only a small part of them proposed and/or mentioned metrics, while the majority of them (although focused or mentioning creativity assessment) did not report any metric (see Figure 2).

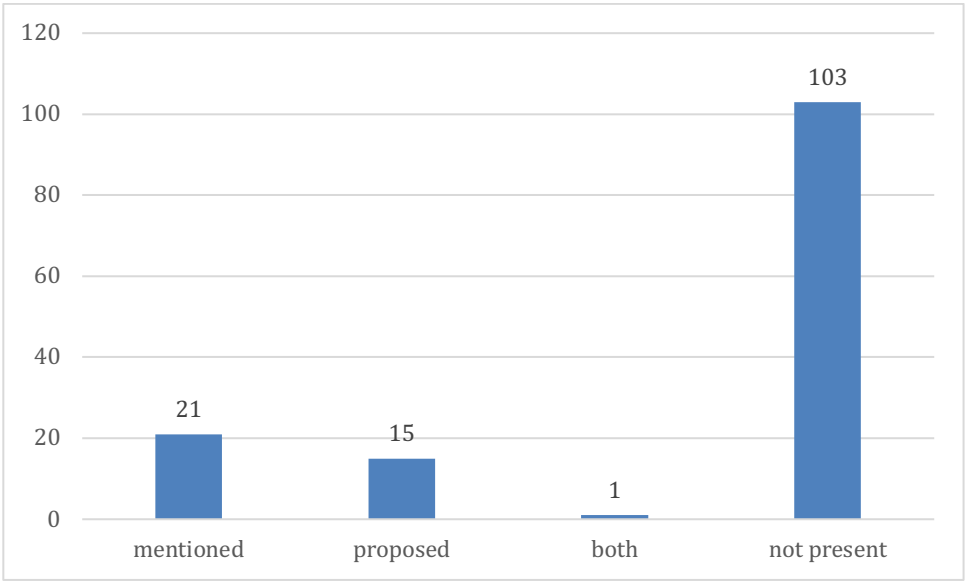

Figure 2. How the reviewed papers talk about novelty metrics.

According to Figure 2, the papers that proposed new metrics were 16 (i.e. 15 that only proposes and one that both proposes and mentions metrics), while those that only mentioned already available metrics were 21.

Then, the considered articles have been analyzed in order to identify both the novelty concept and the creativity family that underpins the related metrics.

The results of this detailed analysis are reported in the next subsections.

3.2. Classification of the reviewed metrics

The metrics described in the articles that passed the screening and the quality appraisal processes relied on different novelty concepts. Additionally, the same term sometimes is used in different articles to refer to different novelty concepts. For instance, the term "Originality" is used by [43] to refer to the inverse probability that similar ideas appear. Differently, Sarkar and Chakrabarti (2011) consider "Original" those ideas that never appeared before. Moreover, different terms sometimes have been used to express the same novelty concept (i.e. what actually a metric measures). An example for this case is that of the work of [69], where the terms "unexpectedness", "unusualness" and "uncommonness" are used to express what actually their metric assesses (see also [70] for further details). There is a similar case for the term "uniqueness", which has been used by [78] for a metric based on the same concept used by [43]. Moreover, the same term (uniqueness) has been used by [74] to express a broader concept of "novelty of ideas within a specific idea generation session", where also a further concept of "Originality" appears (actually a mix of many different novelty concepts).

To reduce the confusion within the context of this paper, the meanings of the different novelty concepts used in the reviewed articles have been extracted and resumed in the set listed and shortly described in Table 2.

Table 2. Novelty concepts

Novelty concept	**Description**
Originality	An idea (or part of an idea) is original if never conceived before.
Uncommonness	An idea is uncommon, unexpected or unusual if it is rarely conceived. This novelty concept is based on the number of times that similar ideas appear.
Newness	An idea or a product is new if it has been recently conceived. This concept, is based on the chronological order with which ideas appear.
Perceived (multiple concepts)	With this term, multiple concepts are considered, which can make an idea "novel" for an evaluator (e.g. newness, unexpectedness, originality, surprise, unconventionality, etc.)

The novelty concepts listed in Table 2 are used to classify the metrics proposed in the reviewed articles (see Table 3).

By exploiting the set of definitions described in Table 2, it has been then possible to associate the specific novelty concepts to the metrics described in the reviewed papers (see Table 3). Additionally, also the Creativity type (i.e. P-Creative vs H-Creative) has been identified, and the metrics have been furtherly discerned in "Value assigned" and "Value calculated" (see Table 3). The first type concerns the metrics that substantially do not need any calculation, but the scores are directly assigned by the evaluator (e.g. by selecting a value between a pre-defined range). In the second type, of course some values need to be assigned, but they do not directly represent the overall novelty score of the idea. The latter is obtained in the "Value calculated" metrics by means of one or more equations.

In some cases, in one or more of the three identification categories (i.e. creativity type, novelty concepts and metric type), it was necessary to assign multiple values. For instance, in the work of Shah and colleagues [69], two distinct types of metrics were cited, i.e. the a-posteriori and the a-priori ones. The first is a value-calculated type of metric belonging to the P-Creative group [27, 73], while the a-priori one is a value-assigned type that allows H-Creative assessments. Differently, for the metrics of [66] and [72], it was necessary to assign both "newness" and "originality" in the "novelty concept" field, because the authors clearly mentioned both concepts in their papers. Similarly, also for [31] it was necessary to assign two different novelty concepts, because the paper presented two metrics (one based on the uncommonness concept, and the other on the perceived novelty). For the articles of [60] and [73] it was necessary to perform multiple assignments in all the three categories. Indeed, in the work of [60], two distinct metrics were used. One based on the uncommonness, with calculated values that allow P-Creative evaluations (for what they call as "Comparative Creativity Assessment"). The other, based on the perceived novelty concept, which allowed H-Creativity evaluations with assigned values (for what they call "Multi Point Creativity

Assessment"). Similarly, the work of [73] considered three different metrics, which led to the multiple assignment (one of them was the already existent metric of [69]).

Table 3. Classification of the reviewed articles presenting new metrics. The classification is based on the metric(s) proposed in each article. In particular, the considered definitions of novelty concepts are those listed in Table 2.

	Creativity type		**Novelty concepts**				**Metric type**	
Article	**P-Creative**	**H-Creative**	**Originality**	**Uncommonness**	**Newness**	**Perceived**	**Values assigned**	**Values calculated**
[43]	x			x				x
[69]	x	x		x			x	x
[66]		x	x		x		x	
[62]		x	x				x	
[78]	x			x				x
[60]	x	x		x		x	x	x
[58]	x			x			x	
[72]		x	x		x		x	
[19]		x				x	x	
[74]	x	x		x		x	x	x
[55]		x		x				x
[39]	x	x		x			x	
[81]	x			x			x	
[31]	x	x		x		x	x	
[79]	x			x				x
[34]		x		x				x

Concerning the 21 papers that only mentioned novelty metrics, they have been analyzed in the same way. Therefore, excluding the references to the metrics already listed in Table 3, only four additional metrics have been identified (Table).

In particular, the metric of [56] was mentioned in in the two works of Chulvi et al. [14, 15], and was used to assess novelty in term of uncommonness. The metric of [23] was mentioned by [30] and [65]. Charyton et al. [10] were mentioned in [11, 12]. However, it is important to notice that the

originality metric of the "Creative Engineering Design Assessment" (or CEDA) is based upon the work of [32]. Eventually, Besemer and O'Quin [7] have been mentioned in the work of [77].

Table 4. Classification of the metrics mentioned in the reviewed articles, which are different from those listed in Table 3.

	Creativity type		**Novelty concepts**				**Metric type**	
Article	**P-Creative**	**H-Creative**	**Originality**	**Uncommonness**	**Newness**	**Perceived**	**Values assigned**	**Values calculated**
[10]		x				x	x	
[23]		x				x	x	
[56]		x		x			x	
[7]		x				x	x	

4. Discussion

4.1. About the achieved results

The performed literature review allowed to identify the most acknowledged metrics for novelty assessment of generated ideas, and to classify them in terms of creativity concepts, novelty concepts and metric type. This is the first clear results that can be attributed to this work, because the variety of metrics ad definitions makes it hard to orient through the number of currently available assessment procedures. To overcome this problem, the set of resumed novelty concepts listed in Table 2 is crucial. Indeed, by referring to Table 2, it is now possible to clearly identify which is the actual novelty concept used in the reviewed metrics. Therefore, those scholars and/or practitioners that need to identify a suitable metric for their specific purposes (and then with a well-defined novelty concept in mind), can use Tables 3 and 4 to rapidly find the most acknowledged ones. Similarly, the classification of metrics among the P-Creative (i.e. what is new for the designer) and H-Creative (i.e. what is new for all people) concepts, allows scholar and/or practitioners to easily find the metrics according to the needed creativity type. To this end, it is possible to assert that while P-Creative metrics are well suited for creativity related purposes, it is not possible to use them for

Innovation assessments, because do not use any reference to the actual state of the art about the designed product. Indeed, since Innovation refers to the actual state of the art for a specific product category, it is necessary to consider metrics that do no limit the reference universe to the set of assessed ideas. Differently, H-Creative novelty concepts can be well suited for Innovation-related assessments, but can lead to additional complications when used for certain experimental purposes, e.g. to compare the creative performance of two different designers (or groups of designers), whose actual knowledge of the state of the art is different.

Therefore, it is possible to provide an important suggestion for those that need to identify a suitable novelty metric. Indeed, before starting to analyse data, it is important to clearly understand which are actually needs to be measured. In other words, we suggest the following steps:

- Identify the creativity type that should be expected for the novelty metric.
- Identify the novelty concepts that fit with the experimental purposes.
- For a more practical point of view, reflect about the possibility of having a mere novelty assignment or a more complex novelty calculation.

Once these reflections have been performed, the user can exploit the contents of this work in order to rapidly identify the subset of articles containing the information about the required novelty metrics.

4.2. Limits and future developments

The search strategy adopted in this work has been tailored to successfully overcome the problem highlighted in Section 2. Unfortunately, although the most acknowledged metrics have been identified, some recent works have been neglected. For instance, it is important to highlight that concerning the a-posteriori novelty metric proposed by shah and colleagues, there are a lot of studies that discuss the related problems and/or try to propose alternatives claimed to overcome them [24, 26, 44, 61, 71]. Actually, the proposal of [80] listed in Table 3 is an attempt to modify the a-posteriori metric of Shah et al., but some issues have been recently highlighted, which can lead to misleading results [24]. Additionally, besides the contribution listed in Table 3, the same authors presented a slightly different metric [80]. Similarly, the metric proposed by [66] has been examined by [41, 42], who found some issues and proposed some possible solutions to overcome them.

Moreover, the research field in the Scopus search engine has been intentionally restricted to "engineering". This led to the exclusion of other possible novelty metrics, perhaps used in other contexts. Future studies should therefore aim at extending the review to other disciplines, in order to check for other metrics and the related novelty concepts. This could be the cause that led to only two articles about patent-related applications (i.e. [34, 49]). It implies that according to the adopted search strategy, such patent-related novelty metrics are not among the most cited/used for engineering design applications. Anyhow, with only two papers it is impossible to extract comprehensive information about these specific kind of metrics, which surely deserves to be examined with particular attention. In particular, an important hint for future research consists in investigating about the compatibility of the reviewed metrics (not only the two patent-related mentioned above) with the procedures used for assessing the originality of inventions by patent

offices. Indeed, the current patent evaluation process is strongly based on the subjective evaluation of the experts in specific fields. The adoption of more systematic assessment procedure could at least support such experts in performing the originality evaluation. However, this paper, for the limitations reported above, cannot support this kind of research.

Furthermore, the set of novelty definitions (Table 2) and the performed classification of the reviewed metrics (Tables 3 and 4) allow to perform studies about metric selection guidelines, based (for instance) on the suggestions provided in Subsection 4.1. For this purpose, an additional review of the same articles considered in this paper could be performed in order to extract the motivations that led to the adoption or the proposal of the specific metric. Therefore, the outcomes of this literature review cannot substitute a comprehensive metric comparison performed by testing them in real cases. However, the proposed classification can be used as a preliminary reference planning such research activities. Indeed, the possibility to discern the underpinning Creativity type, novelty concept and metric types allows to systematically plan experiments (e.g. separating H-Creative metrics from P-Creative ones) perform comparisons (e.g. among metrics sharing the same novelty concept).

4.3. Expected impact

The impact expected for this work is not limited to the research field but also practitioners involved in both creativity and innovation assessments can beneficiate from it. Accordingly, the paper provides a comprehensive list of the most used and acknowledged novelty metrics, classified according to key parameters (see Table 3 and 4). Thanks to this classification, and to the suggestions provided in Subsection 4.1, anyone can now rapidly identify the metric that better fit the specific purposes. For instance, researchers involved in a design experiment where there is the need to assess the novelty of generated ideas can use this work as a reference for metric identification. Additionally, practitioners that need to assess novelty of ideas generated in a firm (e.g. to select the most promising ones or to compare the skills of different persons), can find a valuable and robust reference in this work, thanks to the considered SLR approach.

5. Conclusions

The systematic literature review performed in this paper allowed to identify a set of contributions mentioning and/or proposing novelty metrics to be used in creativity-related assessments (37 in total). The papers have been reviewed in order to comprehensively understand which were the related underpinning creativity concepts, and the specific novelty concepts. It has been found that several and sometimes contradicting definitions of novelty can be found in the engineering literature, thus making hard to use them to classify metrics. Therefore, a set of four definitions has been used here in order to identify specific novelty concepts used in the reviewed contributions. It allowed to obtain a classification of the contributions in terms of:

- The underpinning concept of creativity
- The underpinning concept of novelty
- The type of metric (i.e. “values calculated” vs “values assigned”)

This result is of fundamental importance for both researchers and practitioners involved in creativity assessments of generated ideas. In particular, this is of fundamental importance when trying to identify design ideas that can potentially become an innovation.

The systematic literature review allowed a robust procedure for the selection of valuable and meaningful contributions. However, it implicitly led to the limits of this work, that substantially concern the impossibility to consider all the proposals and the variants that are available for the reviewed metrics. However, as explained in Section 4, this paper paves the way for a series of studies focused on in-depth reviews of novelty metrics used in engineering design, with the final aim to extract comprehensive guidelines for metric selection.

References

[1] **Aksnes DW, Langfeldt L, Wouters P** (2019) Citations, Citation Indicators, and Research Quality: An Overview of Basic Concepts and Theories. SAGE Open 9. doi: 10.1177/2158244019829575

[2] **Alavi M, Joachimsthaler EA** (1992) Revisiting DSS implementation research: A meta-analysis of the literature and suggestions for researchers. MIS quarterly 16:95–116

[3] **Alavi M, Leidner DE** (2001) Review: Knowledge management and knowledge management systems: Conceptual foundations and research issues. MIS quarterly 25:107–136

[4] **Allison CK, Stanton NA** (2020) Ideation using the "Design with Intent" toolkit: A case study applying a design toolkit to support creativity in developing vehicle interfaces for fuel-efficient driving. Applied Ergonomics 84:103026. doi: 10.1016/j.apergo.2019.103026

[5] **Amabile TM** (1983) The Social Psychology of Creativity. Springer-Verlag, New York

[6] **Amabile TM, Conti R, Coon H, Lazenby J, Herron M** (1996) Assessing the work environment. The Academy of Management Journal 39:1154–1184

[7] **Besemer S, O'Quin K** (1986) Analyzing Creative Products: Refinement and Test of a Judging Instrument. The Journal of Creative Behavior 20:115–126. doi: 10.1002/j.2162-6057.1986.tb00426.x

[8] **Boden MA** (2009) Computer models of creativity. AI Magazine 30:23–34

[9] **Bornet C, Brangier E** (2016) The effects of personas on creative codesign of work equipment: an exploratory study in a real setting. CoDesign 12:243–256. doi: 10.1080/15710882.2015.1112814

[10] **Charyton C, Jagacinski RJ, Merrill JA** (2008) CEDA: A Research Instrument for Creative Engineering Design Assessment. Psychology of Aesthetics, Creativity, and the Arts 2:147–154. doi: 10.1037/1931-3896.2.3.147

[11] **Charyton C, Jagacinski RJ, Merrill JA, Clifton W, Dedios S** (2011) Assessing creativity specific to engineering with the revised Creative Engineering Design Assessment. Journal of Engineering Education 100:778–799. doi: 10.1002/j.2168-9830.2011.tb00036.x

[12] **Charyton C, Merrill J a.** (2009) Assessing general creativity and creative engineering

design in first year engineering students. Journal of Engineering Education 98:145–156. doi: 10.1002/j.2168-9830.2009.tb01013.x

[13] **Chechurin L, Borgianni Y** (2016) Understanding TRIZ through the review of top cited publications. Computers in Industry 82:119–134. doi: 10.1016/j.compind.2016.06.002

[14] **Chulvi V, Mulet E, Chakrabarti A, López-Mesa B, González-Cruz C** (2012) Comparison of the degree of creativity in the design outcomes using different design methods. Journal of Engineering Design 23:241–269. doi: 10.1080/09544828.2011.624501

[15] **Chulvi V, Mulet E, Felip F, García-García C** (2017) The effect of information and communication technologies on creativity in collaborative design. Research in Engineering Design 28:7–23. doi: 10.1007/s00163-016-0227-2

[16] **Cross N, Dorst K** (2001) Creativity in the design process: co-evolution of problem–solution. Design Studies 22:425–437. doi: 10.1016/S0142-694X(01)00009-6

[17] **Daly SR, Mosyjowski EA, Seifert CM** (2014) Teaching creativity in engineering courses. Journal of Engineering Education 103:417–449. doi: 10.1002/jee.20048

[18] **Daly SR, Yilmaz S, Christian JL, Seifert CM, Gonzalez R** (2012) Design Heuristics in Engineering. Journal of Engineering Education 101:601–629

[19] **Demirkan H, Afacan Y** (2012) Assessing creativity in design education: Analysis of creativity factors in the first-year design studio. Design Studies 33:262–278. doi: 10.1016/j.destud.2011.11.005

[20] **Doheim RM, Yusof N** (2020) Creativity in architecture design studio. Assessing students' and instructors' perception. Journal of Cleaner Production 249:119418. doi: 10.1016/j.jclepro.2019.119418

[21] **Elsevier** (2020) SCOPUS website. www.scopus.com. Accessed 14 Jul 2020

[22] **Fink A** (2014) Conducting Research Literature Reviews: From the Internet to Paper. Sage Publications Inc, Washington DC

[23] **Finke RA** (1990) Creative Imagery. Discoveries and Inventions in Visualization. Lawrence Erlbaum Associates, Hillsdale, NJ

[24] **Fiorineschi L, Frillici FS, Rotini F** (2019) Orienting Through the Variants of the Shah A-Posteriori Novelty Metric. In: Proceedings of the Design Society: International Conference on Engineering Design. Delft - The Netherlands, pp 2317–2326

[25] **Fiorineschi L, Frillici FS, Rotini F** (2019) Three-Dimensional Approach for Assessing Uncommonness of Ideas. In: Proceedings of the Design Society: International Conference on Engineering Design. Delft - The Netherlands, pp 229–238

[26] **Fiorineschi L, Frillici FS, Rotini F** (2020) Impact of Missing Attributes on A Posteriori Novelty Assessments. Research in Engineering Design 31:221–234. doi: 10.1007/s00163-020-00332-x

[27] **Fiorineschi L, Rotini F** (2019) A-Posteriori Novelty Metrics Based on Idea Decomposition. International Journal of Design Sciences and Technology 23:187–209

[28] **Garcia R, Calantone R** (2002) A critical look at technological innovation typology and innovativeness terminology: a literature review. Journal of Product Innovation

Management 19:110–132. doi: 10.1111/1540-5885.1920110

[29] **Gogos C, Kodonas K, Fardi A, Economides N** (2020) Top 100 cited systematic reviews and meta-analyses in dentistry. Acta Odontologica Scandinavica 78:87–97. doi: 10.1080/00016357.2019.1653495

[30] **Goldschmidt G, Smolkov M** (2006) Variances in the impact of visual stimuli on design problem solving performance. Design Studies 27:549–569. doi: 10.1016/j.destud.2006.01.002

[31] **Gosnell CA, Miller SR** (2015) But Is It Creative? Delineating the Impact of Expertise and Concept Ratings on Creative Concept Selection. Journal of Mechanical Design 138:021101. doi: 10.1115/1.4031904

[32] **Guilford JP** (1984) Varieties of Divergent Production. The Journal of Creative Behavior 18:1–10. doi: 10.1002/j.2162-6057.1984.tb00984.x

[33] **Harrington H, Voehl F** (2013) Innovation management: A breakthrough approach to organizational excellence-Part 1. International Journal of Innovation Science 5:213–224. doi: 10.1260/1757-2223.5.4.213

[34] **He Y, Luo J** (2017) The novelty "sweet spot" of invention. Design Science 3:1–22. doi: 10.1017/dsj.2017.23

[35] **Hennessey BA, Amabile TM, Mueller JS** (2011) Consensual Assessment, 2nd ed. Academic Press, San Diego

[36] **Herrmannova D, Patton RM, Knoth P, Stahl CG** (2018) Do citations and readership identify seminal publications? Scientometrics 115:239–262. doi: 10.1007/s11192-018-2669-y

[37] **Hoerl RW, Gardner MM** (2010) Lean six sigma, creativity, and innovation. International Journal of Lean Six Sigma 1:30–38. doi: 10.1108/20401461011033149

[38] **Hose JL** (2000) Guided wave nuances for ultrasonic destructive evaluation. IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control 47:575–583

[39] **Howard TJ, Culley S, Dekoninck E a.** (2011) Reuse of ideas and concepts for creative stimuli in engineering design. Journal of Engineering Design 22:565–581. doi: 10.1080/09544821003598573

[40] **Howard TJ, Dekoninck EA, Culley SJ** (2010) The use of creative stimuli at early stages of industrial product innovation. Research in Engineering Design 21:263–274. doi: 10.1007/s00163-010-0091-4

[41] **Jagtap S** (2016) Assessing Design Creativity: Refinements to the Novelty Assessment Method. In: International Design Conference - DESIGN 2016. Cavtat, Dubrovnik - Croatia, pp 1045–1054

[42] **Jagtap S** (2019) Design creativity: refined method for novelty assessment. International Journal of Design Creativity and Innovation 7:99–115. doi: 10.1080/21650349.2018.1463176

[43] **Jansson DG, Smith SM** (1991) Design fixation. Design Studies 12:3–11. doi: 10.1016/0142-694X(91)90003-F

[44] **Johnson TA, Caldwell BW, Cheeley A, Green MG** (2016) Comparison and Extension

of Novelty Metrics for Problem-Solving Tasks. In: Proceedings of the ASME 2016 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference IDETC/CIE 2016. Charlotte, North Carolina

[45] **Kazanjian RK, Drazin R, Glynn MA** (2000) Creativity and technological learning: The roles of organization architecture and crisis in large-scale projects. Journal of Engineering and Technology Management - JET-M 17:273–298. doi: 10.1016/S0923-4748(00)00026-6

[46] **Lavie T, Tractinsky N** (2004) Assessing dimensions of perceived visual aesthetics of web sites. International Journal of Human-Computer Studies 60:269–298. doi: https://doi.org/10.1016/j.ijhcs.2003.09.002

[47] **Leenders RTAJ, Van Engelen JML, Kratzer J** (2003) Virtuality, communication, and new product team creativity: A social network perspective. Journal of Engineering and Technology Management - JET-M 20:69–92. doi: 10.1016/S0923-4748(03)00005-5

[48] **Leydesdorff L, Bornmann L, Comins JA, Milojević S** (2016) Citations: Indicators of Quality? The Impact Fallacy. Frontiers in Research Metrics and Analytics 1:1–15. doi: 10.3389/frma.2016.00001

[49] **Li Z, Tate D, Lane C, Adams C** (2012) A framework for automatic TRIZ level of invention estimation of patents using natural language processing, knowledge-transfer and patent citation metrics. CAD Computer Aided Design 44:987–1010. doi: 10.1016/j.cad.2011.12.006

[50] **Linsey JS, Clauss EF, Kurtoglu T, Murphy JT, Wood KL, Markman a. B** (2011) An Experimental Study of Group Idea Generation Techniques: Understanding the Roles of Idea Representation and Viewing Methods. Journal of Mechanical Design 133:031008. doi: 10.1115/1.4003498

[51] **Livne E, Weisshaar TA** (2003) Aeroelasticity of nonconventional airplane configurations - Past and future. Journal of Aircraft 40:1047–1065. doi: 10.2514/2.7217

[52] **Maimon OZ, Horowitz R** (1999) Sufficient conditions for inventive solutions. IEEE Transactions on Systems, Man and Cybernetics Part C: Applications and Reviews 29:349–361. doi: 10.1109/5326.777071

[53] **Mohammadi-Ghazi R, Welsch RE, Büyüköztürk O** (2020) Kernel dependence analysis and graph structure morphing for novelty detection with high-dimensional small size data set. Mechanical Systems and Signal Processing 143:106775. doi: https://doi.org/10.1016/j.ymssp.2020.106775

[54] **Molléri JS, Petersen K, Mendes E** (2018) Towards understanding the relation between citations and research quality in software engineering studies. Scientometrics 117:1453–1478. doi: 10.1007/s11192-018-2907-3

[55] **Moreno DP, Blessing LT, Yang MC, Hernández AA, Wood KL** (2016) Overcoming design fixation: Design by analogy studies and nonintuitive findings. Artificial Intelligence for Engineering Design, Analysis and Manufacturing: AIEDAM 30:185–199. doi: 10.1017/S0890060416000068

[56] **Moss J** (1966) Measuring Creative Abilities in Junior High School Industrial Arts. Council of Industrial Arts Teacher Education, Washington DC

[57] **Mumford MD, Gustafson SB** (1988) Creativity Syndrome: Integration, Application, and

Innovation. Psychological Bulletin 103:27–43

[58] **Ocker RJ** (2005) Influences on Creativity in Asynchronous Virtual Teams: A Qualitative Analysis of Experimental Teams. Creativity 48:22–39. doi: 10.1109/TPC.2005.843294

[59] **Okoli C, Schabram K** (2010) A Guide to Conducting a Systematic Literature Review of Information Systems Research. Working Papers on Information Systems 10:1–51. doi: 10.2139/ssrn.1954824

[60] **Oman SK, Tumer IY, Wood K, Seepersad C** (2013) A comparison of creativity and innovation metrics and sample validation through in-class design projects. Research in Engineering Design 24:65–92. doi: 10.1007/s00163-012-0138-9

[61] **Peeters J, Verhaegen PA, Vandevenne D, Duflou JR** (2010) Refined Metrics for Measuring Novelty in Ideation. In: Proceedings of IDMME - Virtual Concept 2010. Bordeaux - France, pp 1–4

[62] **Perttula M, Sipilä P** (2007) The idea exposure paradigm in design idea generation. Journal of Engineering Design 18:93–102. doi: 10.1080/09544820600679679

[63] **Piccoli G, Ives B** (2005) Review: IT-dependent strategic initiatives and sustained competitive advantage: A review and synthesis of the literature. MIS quarterly 29:747–776

[64] **Pislaru M, Herghiligiu IV, Robu IB** (2019) Corporate sustainable performance assessment based on fuzzy logic. Journal of Cleaner Production 223:998–1013. doi: 10.1016/j.jclepro.2019.03.130

[65] **Purcell AT, Gero JS** (1998) Drawings and the design process. Design Studies 19:389–430. doi: 10.1016/s0142-694x(98)00015-5

[66] **Sarkar P, Chakrabarti A** (2011) Assessing design creativity. Design Studies 32:348–383. doi: 10.1016/j.destud.2011.01.002

[67] **Sarkar P, Chakrabarti A** (2015) Creativity: Generic definition, tests, factors and methods. International Journal of Design Sciences and Technology 21:7–37

[68] **Sarmadi H, Karamodin A** (2020) A novel anomaly detection method based on adaptive Mahalanobis-squared distance and one-class kNN rule for structural health monitoring under environmental effects. Mechanical Systems and Signal Processing 140:106495. doi: https://doi.org/10.1016/j.ymssp.2019.106495

[69] **Shah JJ, Kulkarni S V., Vargas-Hernandez N** (2000) Evaluation of Idea Generation Methods for Conceptual Design : Effectiveness Metrics and Design. Journal of Mechanical Design 122:377–384. doi: https://doi.org/10.1115/1.1315592

[70] **Shah JJ, Vargas-Hernandez N, Smith SM** (2003) Metrics for measuring ideation effectiveness. Design Studies 24:111–134. doi: 10.1016/S0142-694X(02)00034-0

[71] **Sluis-Thiescheffer W, Bekker T, Eggen B, Vermeeren A, De Ridder H** (2016) Measuring and comparing novelty for design solutions generated by young children through different design methods. Design Studies 43:48–73. doi: 10.1016/j.destud.2016.01.001

[72] **Srinivasan V, Chakrabarti A** (2010) Investigating novelty-outcome relationships in engineering design. Artificial Intelligence for Engineering Design, Analysis and Manufacturing: AIEDAM 24:161–178. doi: 10.1017/S089006041000003X

[73] **Srivathsavai R, Genco N, Hölttä-otto K, Seepersad CC** (2010) Study of Existing Metrics Used in Measurement if Ideation Effectiveness. In: Proceedings of the ASME 2010 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2010. Montreal - Canada

[74] **Srivathsavai R, Genco N, Katj, Seepersad CC** (2010) Study of Existing Metrics Used in Measurement of Ideation Effectiveness. In: Proceedings of the ASME 2010 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2010. Montreal

[75] **Stauffer DA** (2015) Valuable novelty: A proposed general theory of innovation and innovativeness. International Journal of Innovation Science 7:169–182. doi: 10.1260/1757-2223.7.3.169

[76] **Suganya P, Fathima L, Prabu D, Rajmohan, Prashanthy MR** (2020) Top cited scientific articles published on artificial intelligence in the field of dentistry- a bibliometric analysis. International Journal on Emerging Technologies 11:797–802

[77] **Takai S, Esterman M, Midha A** (2015) An approach to study associations between design concepts and design outcomes. Journal of Mechanical Design, Transactions of the ASME 137:1–12. doi: 10.1115/1.4028992

[78] **Tseng I, Moss J, Cagan J, Kotovsky K** (2008) The role of timing and analogical similarity in the stimulation of idea generation in design. Design Studies 29:203–221. doi: 10.1016/j.destud.2008.01.003

[79] **Vargas-Hernandez N, Okudan GE, Schmidt LC** (2012) Effectiveness Metrics for Ideation: Merging Genealogy Trees and Improving Novelty Metric. In: Proceedings of the ASME 2012 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2012. Chicago, Illinois

[80] **Vargas-Hernandez N, Schmidt LC, Okudan GE** (2012) Systematic Ideation Effectiveness Study of TRIZ. In: Proceedings of the ASME 2012 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2012. pp 1–10

[81] **Vasconcelos LA, Cardoso CC, Sääksjärvi M, Chen C-C, Crilly N** (2017) Inspiration and Fixation: The Influences of Example Designs and System Properties in Idea Generation. Journal of Mechanical Design 139:031101. doi: 10.1115/1.4035540

[82] **Venkatesh V, Davis FD, Morris MG** (2007) Dead or alive? The development, trajectory and future of technology adoption research. Journal of the Association for Information Systems 8:267–286