A Framework for the Dissemination of Design Research Focused on Innovation

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Abstract This contribution presents an original framework for transferring the results of design research into practice, specifically addressing the need of creating a circle of players from various companies interested in being part of both the mass dissemination process of already tested methodologies and in pilot experiences and preliminary dissemination activities with the latest design research developments. Moreover, the paper focuses the attention on the existing metrics for evaluating the impact and the viability of adoption of design methodologies in practical contexts, showing their lacks in covering aspects mostly related to the dissemination of design research concepts. An original metric is described and applied to six case studies of industrial interest that have been carried out, with the objective of consolidating the acquisition of skills through the practical application of more theoretical elements, by employees of industries that have already received a basic training. The main results are discussed also with a broader perspective, so as to highlight the potential benefits deriving from the adoption of a shared metrics to measure this kind of knowledge transmission from design research to practical applications.

1 From Scientific Research to Mass Dissemination: A Pattern to Be Empowered

The path connecting scientific research to the mass dissemination of the research outcomes usually consists of different steps where several players contribute to the transition from research to practice.

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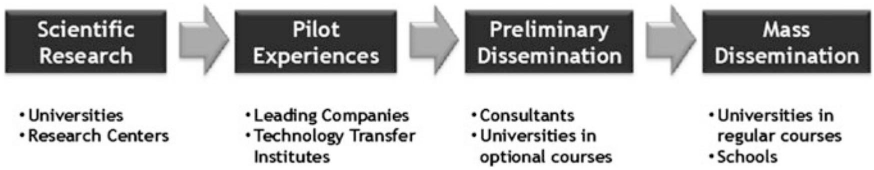

Fig. 1 A typical path for transferring engineering research toward mass dissemination. Red boxes represent common stages of diffusion; bullets summarize the main players involved in each stage

Figure 1, for instance, describes a typical path by which the results of research in the design domain get consolidated and progressively spread to a bigger audience.

Universities play a relevant role in several stages of this diffusion process: together with research centers they generate new knowledge, produce new theoretical developments and, moreover, they contribute in the dissemination process by educating future generations of practitioners and scholars. Besides, companies with a strong innovating behavior that usually are leaders in the reference market, are the most likely subjects interested in carrying out pilot experiences on the basis of the latest research outcomes. Technology transfer institutes usually play an auxiliary role along these processes, also by connecting academia and industries. After the success of pilot experiences, consultants and vendors contribute to the preliminary dissemination and, in some case, they independently improve specific techniques for focused applications in industry. As said, universities start introducing optional classes in their courses that, with a longer perspective, would become part of regular academic courses as well as topics in schools.

This path is now consolidated and there exist several examples of this transition for design tools. For instance, all the different generations of CAD systems (from 2D/3D CAD through CAM and CAE to PLM and Multiphysics applications) diffuse according to this process, with the concurrent support of vendors pushing for their spreading in later stages. However, the situation is different for what concerns the diffusion of conceptual design methods. Indeed, courses on CAD tools are nowadays present in all the industrial curricula of universities. On the contrary, classes on design methods, even those more renowned as Six Sigma or FMEA/FMECA, are not usually offered as mandatory academic courses apart from few exceptions. In this context, design methods, meant as specific procedures, techniques, tools, etc. aimed at improving effectiveness and efficiency of design processes, suffer from the lack of subjects pushing their dissemination in the long term: after the preliminary dissemination stage, this absence may trigger a drop in the interest of a wider audience. From this perspective, it appears as more and more important to trigger new motivations in potential adopters and define adequate subjects capable of fostering the diffusion of design methods.

To this purpose, this paper presents a framework to foster the diffusion of design research into practice, so as to improve the above-mentioned transition and sustain the dissemination with a longer perspective. Moreover, the authors define a tailored metric to measure the impact and the viability of this transition.

The next section introduces the metric and the methods of measurement of main interests for the purpose of the paper. Sections 3 and 4, respectively, present the original framework for sustaining the diffusion of design research toward its practical application in the long term and the metric to measure one of the steps of this transition. Section 5 shows how the metric has been applied and what kind of information it allows to map after the application of design methods by practitioners that have received dedicated vocational courses in companies. Then, the authors discuss the main evidences emerged after the application of the metric, as well as its strengths and weaknesses. Specific concluding remarks focus on the potential benefits triggered by the adoption of a shared metric for assessing the transition of design research into practice.

2 Design Outcomes and Design Process: Metrics for Their Evaluation

As mentioned in Sect. 1, since this paper focuses the attention on the impact and the viability of the practical application of design methods that influence both the design outcomes and the related processes, the authors briefly review the most acknowledged approaches and metrics for evaluating them. Still trying to produce a list of reference criteria as exhaustive as possible, the authors decided to put more emphasis on the practical implications of measures, rather than focusing on the different perspectives that are still debated in academic literature.

2.1 Object of the Measurement

The measure of a designing activity usually gets carried out with the purpose of evaluating the creativity expressed during the idea generation stage. Several contributions (e.g. Sarkar and Chakrabarti 2011) already review the different approaches available in literature. Despite the various viewpoints, there is a strong and shared orientation among scholars in considering some of the requirements for patentability as the most relevant features characterizing the creativity of newly generated ideas. Usefulness usually describes the suitability of the generated idea to practically solve a problem, or more generally a situation with discontentment. Novelty, in turn, indicates the conceptual distance of the idea from what existed before. The non-obviousness and the surprise, as well, are concepts related to the unexpectedness of the idea, respectively, concerning the one who generates it and those observing it.

On the other hand, some constructs have been proposed also for measuring the characteristics of the design process. Shah et al. (2003), for instance, proposed the introduction of two constructs, so as to produce meaningful insights about the creativity of the design process: variety and quantity. Both of them take into account all the ideas generated while designing. Variety considers the range of diversity resulting between solution concepts and quantity simply counts the productivity of the process in terms of the overall number of generated ideas.

The measurement of the quantity of ideas underlies the assumption that the probability of finding a good idea in a set of generated ideas is higher the bigger is the set (Osborn 1963). Nevertheless, this approach completely overlooks the assessment of the efficiency of the design process that can be measured in terms of resources devoted to the generation and the development of solutions (people, time, …) (Becattini et al. 2012).

At last, it is also worth mentioning that, in the logic of transferring the knowledge from theory to practice, there are relevant metrics tailored for specific purposes. Since this topic goes beyond the purposes of this paper, it is sufficient mentioning that correctness and completeness represent two among the most diffused criteria to evaluate the correct application of theoretical teachings to students of different subjects and of different ages.

2.2 *Method of the Measurement*

Different methods are used to assess the constructs presented in Sect. 2.1 and literature shows a particular attention on the quantification of these measures with numerical indicators. Nevertheless, some methods of measurement go beyond the design outcomes and the related process and aim at measuring also the creativity of individuals, with appropriate criteria. The Torrance Test for Creative Thinking (e.g. in Almeida et al. 2008) is a clear example of method for measuring the creativity of individuals after the administration of a test. It supports the definition of individual's creativity according to process-related constructs, almost completely overlapped with the ones proposed in Sect. 2.1 (e.g. flexibility matches with variety, fluency with quantity, etc.).

A more empirical method for assessing the thinking process of individuals and groups involved in design activities concerns the examination of their behaviors. This approach goes under the name of protocol analysis; a review of different protocol analysis approaches is available in Jiang and Hen (2009). Scholars have developed several methods and tools for improving this kind of analysis as, for instance: coding schemes (e.g. Gero and Kannengiesser 2004), criteria for segmenting the protocols (e.g. Suwa et al. 1998), as well as specific applications (Gero et al. 2011). For instance, linkography (Goldschmidt and Tatsa 2005) is a technique to represent the mutual relationships between ideas during a design process. This technique supports both the analysis of the protocols and enables a more straightforward application of specific metrics, as for the ones measuring the divergence/convergence of the thinking process or its entropy, as for Kan et al. (2007).

As for the learning process, there are different approaches to evaluate the different outcomes of students of various ages and experiences. Nevertheless, the different measures can be distinguished in objective or subjective, according to the kind of administered tests as, for instance, the objective tests developed within the OECD Programme for International Students Assessment—PISA (OECD, 2002).

From a very different perspective, professional certifications represent the other side of the approaches for evaluating the learning outcomes of trainees of vocational courses. However, the authors believe that this kind of method is not adequate for the evaluation of the impact of design research, since it is mostly suited for the evaluation of already consolidated theories, whose application has been already tested in several practical applications.

2.3 Metrics to Evaluate the Diffusion of Design Methodologies

With reference to the overall logic of the paper, it is also necessary mentioning the need for evaluating the diffusion of design methods and their perceived impact. To this purpose, a relevant example is the worldwide survey that the European TRIZ Association (ETRIA) carried out in 2009 (Cavallucci 2009) about the perception and the uses of TRIZ, Russian acronym for Theory of Inventive Problem Solving (Altshuller 1984). In that context, several aspects were observed, such as:

- the width of the knowledge in use with respect to the theoretical entire Body of Knowledge of TRIZ and the most commonly used concepts and tools;
- the size and the composition of research structures where TRIZ is a research topic;
- the penetration of the TRIZ concepts in the educational domain;
- the size and the technical field of industries using TRIZ within their development cycles;
- the benefits that companies expect as a consequence of the adoption of TRIZ.

3 A Model to Transfer Design Research into Practice: Academia and Center of Competence on Systematic Innovation

The following section presents the approach the authors have experienced during the last 8 years for transferring design research into practice (see Fig. 2).

The big circle at the center of Fig. 2 represents the core of the model since it collects the main players both developing design research and promoting the dissemination and the adoption of design methodologies in common industrial practices. The Yin–Yang (Tao) symbolic parallelism serves to clarify that within this model design research and the dissemination at industrial level are mutually tangled

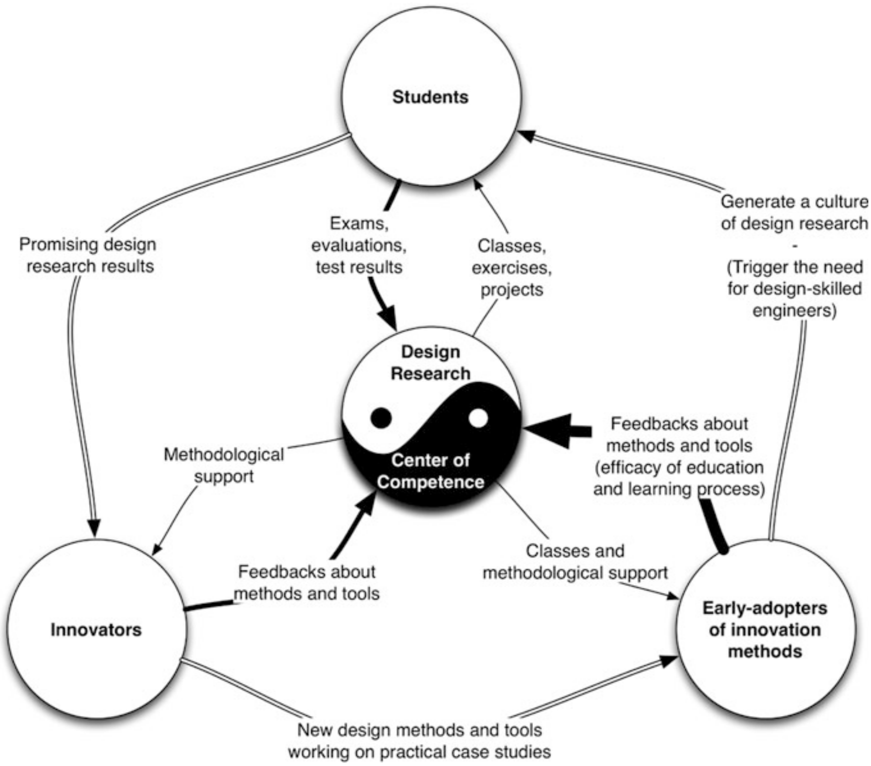

Fig. 2 A graphical description of the approach that links design research, dissemination, and industrial practice. *Thin arrows*: educational approaches; *thick arrows*: evaluation processes; *double arrows*: impacts on the content of the dissemination/education process

by the newly injected concepts from theory and the practical feedbacks coming from practice with design methodologies. The next subsections present the two parts of the Tao symbol.

3.1 Design Research and Its Diffusion in Academia

Both Politecnico di Milano and Università degli Studi di Firenze are carrying out researches on design focusing their attention on specific subjects, such as:

- the definition of new methods and tools for inventive design (e.g. systematic analysis of complex and difficult problems, identification of appropriate stimuli and sources of inspiration, methods and heuristics for problem solving, definition of new models of cognitive processes); and

- knowledge management (e.g. knowledge transfer for idea development, identification of elements for decision-making in technological forecasting and business process reengineering activities, Information Retrieval and Extraction; Intellectual and Industrial Property).

Moreover, both the universities offer classes on design methods that are optional for a wide range of students from different courses and compulsory for those focusing their curricula on machine design. These classes present topics ranging from the general aspects of the product development process to specific problem-solving theories and methodologies; from the management of intellectual property to the identification of relevant knowledge elements supporting the strategic planning of companies.

The dissemination of these concepts aims at educating the next generation of engineers and designers with some of the most advanced and widely experienced outcomes from design research. This transfer of knowledge occurs with different blends of theoretical lessons and practice with exercises and projects (both with and without the support of professors and teaching assistants). Moreover, the evaluation of the whole acquired competences gets carried out both with written and/or oral exams and with the discussion about a project the students developed during the course. This process produces feedbacks to both students and professors: the former better understand what needs to be further improved among their competences; the latter obtain a general picture of the effectiveness of the education process and the structure of the class.

Volunteering students are often involved in optional testing sessions whenever some of the latest design research outcomes require a preliminary validation with a significant amount of testers, so as to draw early but statistically supported evidences. These kinds of tests are usually more operative and strongly structured, so as to clearly define what should be measured during the specific application of, e.g. new tools and methods for design. In other words, these tests are mostly focused on the specific evaluation of characteristics of the research outcomes in order to fix criticalities and remove bottlenecks, rather than focusing on the specific characteristics described in Sect. 2.1.

As a result of this preliminary validation process, the widely tested successful experiences start to be proposed to industries for their pioneering application in industrial practice, as described in Sect. 3.2.

3.2 Center of Competence on Systematic Innovation: Closing the Virtuous Cycle Between Design Research and Practice

The Center of Competence on Systematic Innovation mainly operates in Italy and gathers professors, academic researchers, and experts with the purpose of deepening and diffusing topics concerning problems solving and systematic innovation methodologies to a wide audience: from industries to authorities and individuals (http://www.innovazionesistematica.it). The following players compose the consortium:

- Fondazione Politecnico di Milano;
- Politecnico di Milano—Department of Mechanics;
- University of Bergamo—Department of Industrial Engineering;
- University of Florence—Department of Industrial Engineering;
- Ceris-Institute for Economic Research on Firms and Growth, CNR;
- PIN Scrl.

They are differently involved in both research activities (universities and research centers) and technology transfer practices (Fondazione Politecnico and PIN).

The Center offers two main tracks to companies interested in systematic innovation activities. The first concerns the delivery of courses on innovation supporting methods (such as TRIZ) to individuals or companies (Early adopters in Fig. 2). The training is tailored to suit the profile of the participants (operational roles vs. executives). The second usually involves companies (Innovators in Fig. 2), which have already attended courses offered by the Center or having a more consolidated experience with systematic innovation methodologies. They constitute a sort of set of "retained" partners, available to test the latest research developments, both as new tools for performing established tasks (e.g. modeling complex situations and defining priorities for problem solving), or embedding new tasks in the design process (e.g. integrating technology forecasting as a means to foster radical innovation with higher probability of success).

These two dissemination activities (with early adopters and with innovators) are presented consistently with the anticlockwise order of Fig. 2.

Innovation-oriented companies represent, therefore, the more interested subjects in testing the design research outcomes in practical applications and they can be practically involved with a small or null amount of vocational resources, because of their previous experiences of training or practice. The common aspect pooling the dissemination of diverse research outcomes stands in the educational approach that, beyond a potentially required initial training, leverages the support of methodological experts for the application of methods and tools on real industrial case studies. This kind of approach enables capturing feedbacks about strengths and weaknesses of research developments, with both an "in-progress" and an "a posteriori" perspective. This twofold perspective allows measuring both the characteristics of design methodologies under testing and those mostly related to the industrial practice, such as:

- the accessibility and the possibility to share technical and strategic information;
- dynamics within companies and decisional chains;
- the tendency of individuals and groups to adhere to already developed ideas.

As said, the offer of the Center for early adopters of design methods addresses both the needs of individuals and companies interested in systematic innovation.

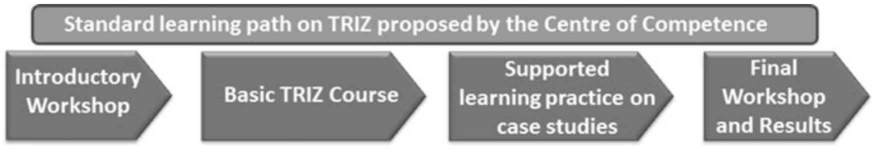

Fig. 3 The standard structure of the dissemination path of TRIZ, as proposed by the center of competence on systematic innovation

These courses are well structured and the topics focus on consolidated theories and research outcomes already tested with success in industrial practice. An example of structured dissemination path is represented in Fig. 3, which refers to TRIZ training.

An introductory workshop presents the philosophy underlying a systematic approach toward technological innovation and describes the structure of the whole training process to all the interested people, especially involving decision makers at different organizational levels that could have higher stakes in participating the training. According to the number of participants, the Center organizes an optimal amount of basic courses, so as to facilitate effective lessons and an adequate active involvement of all the attendees. The course provides operational skills on some specific topics such as structured brainstorming, inventive problem solving, technology scouting through patent mining, etc. After the conclusion of the course, small panels of motivated trainees (2–3 people each) are formed to make them focus on practical case studies of industrial interest. This activity is carried out also with the support of methodological experts that regularly monitors the autonomous application of the taught methods for tutoring and supporting them, with methodological suggestions and contextualized examples. All the solution concepts generated during these practical sessions get collected and ranked and a summarizing report is prepared. During a concluding workshop, the activities of the different panels working on practical problems are presented focusing the attention on both the design process and its outcomes.

A similar logic is followed also within pilot experiences with the so called Innovators, that are both involved in sessions aimed at transferring the use of the new methods and tools and follow-up sessions with practical application of the lessons learned to everyday activities.

Despite the standard approaches presented in Sect. 2 allow mapping many elements of designing and generating ideas, they should be integrated with more customized indexes, so as to properly evaluate the impact and the viability of these dissemination activities. This evaluation represents one of the paramount necessities to retrieve useful feedbacks for improving the newly developed design methodologies and increasing their acceptance and adoption in industrial contexts.

The following Sect. 4 describes the main objective of a metrics addressing this demand and its overall logic.

4 Criteria for Evaluating the Adoption of Design Methods and Tools in Industrial Practice

The assessment of the impact and the viability of newly developed design methods in practical context (the thicker black arrow in Fig. 2) requires both the evaluation of the activities carried out during the design process and its outcomes. Nevertheless, since designing is a knowledge-intensive process (Tomiyama 1994), there are other important elements that go beyond the standard evaluation of design outcomes as generated solution concepts.

To this purpose, the authors propose to evaluate the following elements, as described in the first column of Fig. 4.

Then, the impact evaluation cannot be measured simply through the goodness of newly developed solution concepts, but this measure needs to be compared with already developed solutions, as emerged from the state-of-the-art analysis. Moreover, the novel generated knowledge during the solving process of a design problem represents one of the other elements to be considered, even if its benefits are not directly and immediately measurable through design outcomes.

In turn, beyond what is depicted in Fig. 4, it is also critical to generally measure the usefulness and the viability of the practical application of design methods for the company as a whole. The overall objective is to evaluate or infer the global value of the newly developed concepts for the company and the resources consumed for generating them (e.g. people, knowledge, time).

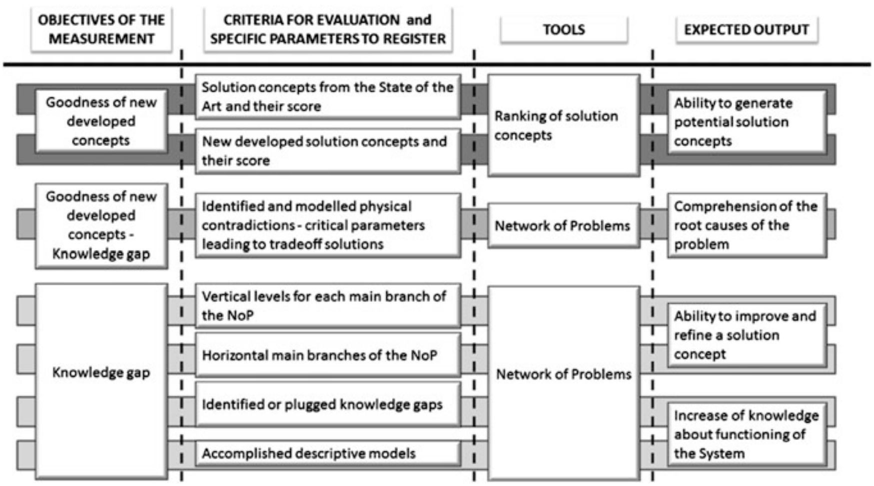

Fig. 4 Synoptic scheme of the proposed metric, with evaluation criteria, tools to be applied and expected impacts on design practices (NoP : Network of Problems)

4.1 OTSM-TRIZ Network of Problems: A Representation of Knowledge About Problems and Solutions

The Network of Problem (NoP) is one of the OTSM-TRIZ instruments (Khomenko et al. 2007) that aims at coping with the analysis of complex problems during a problem-solving process. It is presented in this context because it allows both problems and partial solutions (nodes) to be connected according to their relationships (links) in the same model with the form of a network, thus mapping critical elements to be taken into account for the impact estimation of design methods in practice. Different scholars are progressively improving this technique and one of its latest developments extends its suitability also for mapping design processes (Becattini et al. 2013), using the constructs presented in Fig. 5.

This general framework can be further enriched by nodes of a third type, collecting doubts and highlighting open questions about both problems and partial solutions to be answered before further proceeding along a certain direction of development.

The NoP is characterized by a good versatility, since it is possible to build it during the examination of the case study, as well as with an ex-post approach through the use of audio and video recordings of the design session, consistently with the approach for the analysis of design protocols.

Moreover, once this knowledge map about problems and partial solutions has been built, it just requires progressive updates so as to reuse it for developing poorly

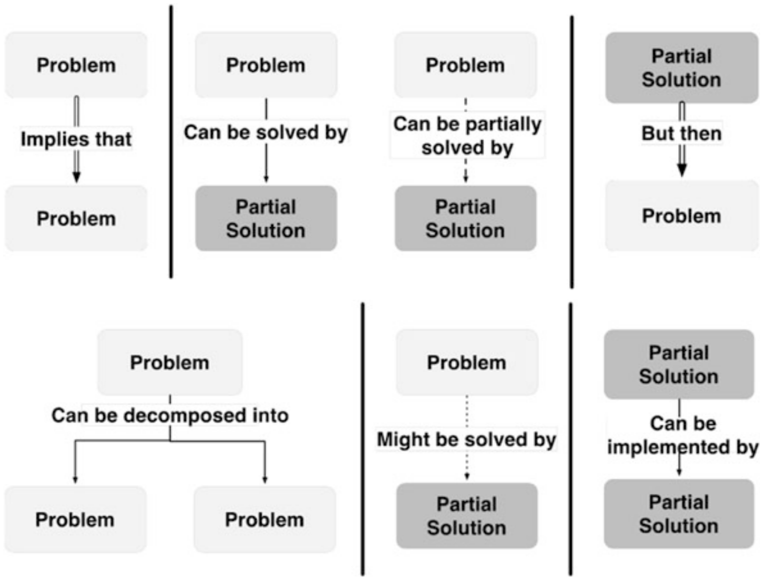

Fig. 5 The main elements and connections to be employed in the network of problems

explored branches of the NoP or for choosing solutions that become more convenient because of changes in the context.

4.2 Description of the Evaluation Metrics Based on the NoP

According to Fig. 4, the proposed evaluation metric consists of seven main criteria on which the impact should be measured both in terms of goodness of solutions and generated knowledge gap.

The number of solutions is counted for both those already known from the state-of-the-art analysis and the newly developed ones, with the purpose of comparing the two sets. This variable tries to extend the common metrics of quantity and fluency.

The score of solution concepts, for both kinds of solutions, gets calculated with the criteria of Weighted Sum Methods (e.g. in Pohekar and Ramachandran 2004). Different technical criteria are defined and weighted for the suitability of solution concepts, which are finally evaluated according to the judgment of decision makers. As for the number of solution criterion, the purpose is to evaluate the impact by comparing the solutions from the state-of-the-art analysis with the newly generated ones. From a practical perspective, this approach helps the designers to properly choose with a more objective approach the solutions to be developed with higher priority.

The identification of critical design parameters (i.e. with conflicting requirements) usually leads to trade-off solutions represents a critical parameter to be evaluated and a relevant criterion for defining the capability of design methods in supporting designers during the identification of the core elements of design problems, whose solution may trigger to brilliant, effective, and efficient ideas.

The number of vertical levels for each main branch of the NoP gives an idea of the convergence toward specific solution concepts through the identification of partial solutions and the new problems they trigger (blue connections in Fig. 6). The higher the number of vertical levels on a branch, the more convergent is the design process toward that final solution concept.

The number of horizontal main branches of the NoP is a criterion that supports the evaluation of the degree of exploration of the different implications and causes of an overall design problem (red rounded box in Fig. 6). Bigger is the number of horizontal branches of the NoP and more intense would have been the analysis. On the other hand, it also supports the estimation of the occurrence of detailing processes for solution concepts (Partial Solutions to Partial Solutions links) and the divergence of idea generation processes (Problems to Partial Solutions links).

The number of identified or plugged knowledge gaps represents, as well, one of the core criterion for the evaluation of the impact that the practical application of design methodologies have in improving the degree of understanding of technical problems. The identification of these knowledge gaps (pink boxes in Fig. 6), once

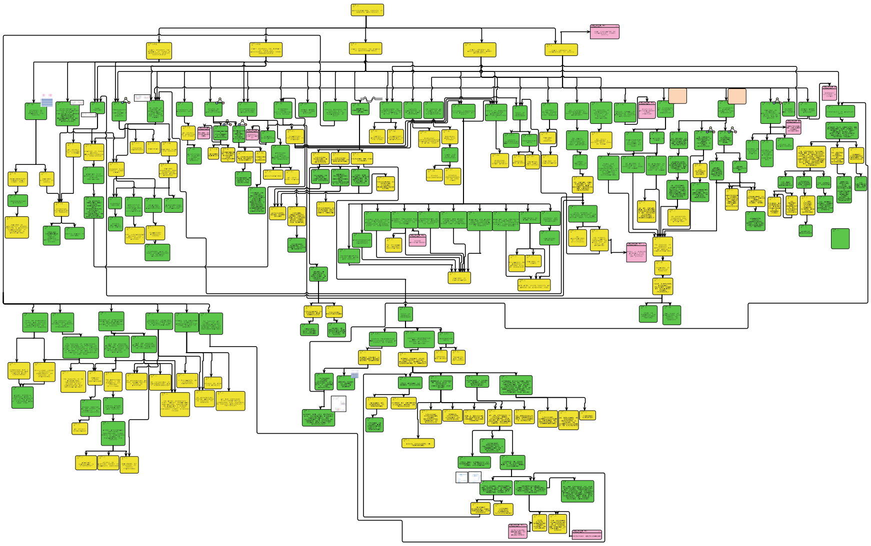

Fig. 6 An example of network of problems. The content of *boxes* is intentionally not readable due to confidentiality issues. *Yellow* and *green boxes*, respectively, correspond to problems and partial solutions (see Fig. 5). *Pink boxes* highlight the need to plug specific knowledge gaps emerged during the analysis of the design problem. The *red horizontal rounded box* spanning five subproblems shows the main branches into which the analysis has been subdivided. The *blue* connections show the path (10 vertical steps) into which the designers have deepened the analysis from one of the main subproblems

plugged, can trigger both the definition of critical design parameters, as well as novel ideas.

The number of accomplished descriptive models supports the evaluation of the frequency of adoption of taught concepts with methods and tools for problem analysis (e.g. one of the subproblems highlighted in the NoP has been examined by means of a functional or by a root cause analysis model). The higher the number of accomplished descriptive models is, the more effective is the dissemination process about instruments for the analysis aimed at improving the understanding of the way a certain system works.

4.3 Evaluation Criterion for Measuring the Overall Usefulness of the Practical Activity

For what concerns the evaluation of the usefulness of the application of design methodologies on industrial case studies, the authors suggest interviewing the involved subjects, so as to capture the opinion of trained people about the expected and the observed outcomes of a structured design activity for systematic innovation and its potential impact on their work.

Besides, it is necessary to avoid diplomatic answers that might hide criticalities, thus reducing the meaning of the feedback for the research activities. In this perspective, and also as a means to encourage the industrial partners for the testing and the adoption of the recommended methods and tools, the Center of Competence for Systematic Innovation proposes a peculiar formula in its training and coaching contracts. In fact, at the end of the coaching session, after the experimental application of the proposed methods and tools on some real case study, companies have to express their assessment on the quality of the design outcomes. A positive assessment implies (by contract) the payment of an extra fee, as a recognition of the success of the activity. A negative assessment allows the company to avoid any further payment beyond the training time, but the Center of Competence gains the possibility to autonomously file a patent application on the emerged solutions and/or to sell the same concepts to other companies. In turn, if the design outcomes are meaningless, the companies can easily reject the payment of the bonus and refuse any exclusive property on them, thus demonstrating a lack of practical benefit beyond any diplomatic comment on the proposed methods and tools. Besides, if they agree to recognize the bonus fee, they confirm the practical validity of the design activity.

5 Application of the Metric: Experiences in Reference Companies

This section presents the application of the metric described above to a number of case studies carried out within coaching sessions similar to the third stage depicted in Fig. 3. The design sessions involved panels of technical experts working under the supervision of methodological facilitators on the solution of tough design problems.

For confidentiality issues it is not possible to directly cite the industries with which the six case studies have been carried out and on which the metric is applied. Nevertheless, their general descriptions are briefly summarized in the following bullet list with the purpose of showing their diversity. The results of the application of the metric are summarized in Table 1.

Case study #1.
The deposition of dust on sensitive surfaces;
Case study #2.
The contamination of goods by nonadequately clean sanitization device;
Case study #3.
The unconformity of geometrical tolerances in a manufacturing process for the assembly of two materials;

Table 1 Summary of the results obtained through the application of the metrics

	Case study #1	Case study #2	Case study #3	Case study #4	Case study #5	Case study #6
# of concepts from the SoA	5	5	4	8	1	7
Score (avg.) for the SoA concepts	259.8	–	–	33.5	8.67	7.78
# of newly developed concepts	11	50	6	14	31	–
Score (avg.) for the newly developed concepts	285.9	–	–	36.4	7.16	–
# of critical design parameters	2	2	1	2	5	6
# of vertical levels per branch of the NoP	3; 1; 7; 3; 3.	4; 3; 10; 3; 7.	4; 4; 3	8; 1; 1; 2; 1; 0.	–	1; 3; 1; 1; 1; 3; 1.
# of main horizontal branches of the NoP	5	5	3	5	–	7
# of identified or plugged knowledge gaps	12	10	13	4	10	12
# of descriptive models	Yes	No	Yes	No	18	2

Case study #4.
The presence of residual mechanical stresses triggered by sudden cooling after welding;
Case study #5.
Manufacturing a planar surface with tight tolerances by removing material;
Case study #6.
The precision of the process of positioning electronic devices.

Given the great variability of the different case studies, it is expected to obtain heterogeneous results in the different columns. However, before commenting the results of this application, it is necessary to start with a general remark. Table 1 shows that along some case studies (e.g. case studies #2 and #3) the designers did not define appropriate criteria for the evaluation of solution concepts and therefore they completely skipped the assignment of weighted scores. Moreover, blank cells for case studies #5 and #6, respectively, inform about the lack of knowledge modeling with the NoP and the complete absence of generated solution concepts. Both these cases have been purposefully chosen so as to point out different but critical aspects. For what concerns Case study #5 it is sufficient to build the NoP with an ex-post approach, if audio or video recordings are available. As for Case study #6, the complete absence of newly generated concepts represents a warning of something wrong in the training program or of a poor availability of resources or interest to properly carry out an appropriate practical application.

The comparison of solution concepts from the state-of-the-art analysis and the ones generated through the support of design methods shows that the adoption of design methods improves the ideation productivity, since in three cases out of six the number of generated ideas is more than the double of the ones already known before the beginning of the activity.

For what concerns the scores of the different solution concepts, the case studies #1 and #3 show better levels for the newly developed solution concepts. On the contrary, the results for the case study #5 present an opposite trend. Moreover, it is also important noticing that the values of this score strongly differs among the different applications, because the involved designers have a complete freedom in choosing the reference scale of evaluation (the scores may vary in the range 0÷1 as well as 1÷10, and so forth).

Considering the development of new knowledge among the results of this tutored design activities, it is worth noticing that all the analyses, at different extents, supported the identification of critical design variables that prevents the development of new and more radical solution concepts and that usually get a trade-off value for finding the best compromise between requirements (a physical contradiction, in the TRIZ jargon).

The examination of the NoP, beyond the aid for counting the different emerged solution concepts, also allows the analysts to obtain relevant elements concerning the divergence and the convergence of the design process, with particular attention to the exploration of solution concepts, their refinement, and the systematic perspective on problem analysis. Moreover, the numbers concerning the development of vertical levels in the NoP also suggest the different degree of involvement of the subjects participating the activities. Panels of experts working on the case studies #1 and #2 show a more intensive participation and application of the dialectical logic behind the identification of partial solutions and subsequently generated problems.

As well, the number of knowledge gaps that are identified or plugged along the analyses also witnesses the knowledge enrichment processes occurring with the practical application of design methods. A final remark concerns the criteria for measuring the adoption of prescriptive models. For some case studies (#1÷4) this evaluation followed just a qualitative approach; on the contrary, for the others it was possible to count the number of times the different models have been used.

6 Toward a Standard Metric for Design Research-to-Practice Transitions: Concluding Remarks

This paper stems from the analysis of the criticalities emerged in the process of disseminating design research outcomes and presents, to this purpose, an original approach for supporting the diffusion of design research methodologies. The authors also propose a metric suitable to capture some elements describing the impact and the viability of the transition to a new generation of design methods than the existing evaluation criteria, as reviewed in Sect. 2, are not mapping.

Figure 2 depicts the overall structure that joins academia, research centers, and institutes for technology transfer in a unique subject, called Center of Competence for Systematic Innovation. Throughout the activities of this Center, several pioneering research outcomes are tested with more innovation-oriented companies. On the contrary, the most consolidated ones get progressively absorbed into the curricula of less basic education course and get diffused to early adopters of design methodologies.

The authors originally developed a metric that specifically addresses the need of measuring the transfer of knowledge to practitioners by focusing the attention on the evaluation of the improvements (in other words, the positive impact) they obtain in both generating valuable ideas and producing new knowledge for the company they work for. The metric is based on criteria for which it is possible to retrieve data from a Network of Problems, a kind of knowledge map that can be produced both during the analysis, as well as with an ex-post perspective, in case recordings of the design activities are available.

In other terms, in order to foster the transfer of design research into practice the authors consider of paramount importance the following:

- Rely on a structure that links together academia and industries, such as a center of competence, with mutual exchanges on research objectives, best practices on design methods, and punctual assessment of the related impact;
- Assess the goodness of the outcomes of design research through intensive tests before their dissemination to a bigger audience. A reliable assessment should consider the effectiveness of the proposed methods and tools by validating them with statistical significance (e.g. by involving students in academia as testers, if needed) and on the field with companies to evaluate their industrial impact;
- Measure the outcomes of the transfer by means of appropriate metrics that also allow the identification of issues and troubles of the applied methods and tools, as well as the need of new ones addressing emerging situations.

For what concerns the further developments of the proposed approach, the authors expect to generate an active debate about the definition of an appropriate structure for subjects transferring design research into practice. Moreover, metrics for quantitatively evaluating the transfer, the impact and the viability of design outcomes and to share the results among scholars involved in design research are critical for obtaining meaningful feedbacks from practitioners. The adoption of a common metric represents a good chance to better exchange the results from the outcomes of design practice among scholars in a unique form, so as to enlarge the number of tests and related feedbacks about the application of design methodologies and better identify the directions for easing its adoption.

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