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Review Article

Analyzing the Synergy between HCI and TRIZ in Product Innovation through a Systematic Review of the Literature

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The boundary between tangible and digital products is getting more fused while rapidly evolving systems for interaction require novel processes that allow for rapidly developed designs, evaluations, and interaction strategies to facilitate efficient and unique user interactions with computer systems. Accordingly, the literature suggests combining creativity enhancement tools or methods with human-computer interaction (HCI) design. The TRIZ base of knowledge appears to be one of the viable options, as shown in the fragmental indications reported in well-acknowledged design textbooks. The goal of this paper is to present a systematic review of the literature to identify and analyze the published approaches and recommendations to support the synergy between HCI and TRIZ from the perspective of product innovation related to HCI, with the aim of providing a first comprehensive classification and discussing about observable differences and gaps. The method followed is the guidelines related to systematic literature review methods. As results, out of 444 initial results, only 17 studies reported the outcomes of the synergy between HCI and TRIZ. The 7 of these studies explored the feasibility of the combination of HCI and TRIZ. The 10 studies attempted to combine and derive approaches in these two fields, and the outcomes defined 3 different integration strategies between HCI and TRIZ. Some conclusions achieved are that the generic solutions to support the synergy between HCI and TRIZ are still rare in the literature. The extraction and combination of different tools caused the randomization of the evaluation criteria, and the performance of the proposals has not been comprehensively evaluated. However, the findings can help inform future developments and provide valuable information about the benefits and drawbacks of different approaches.

1. Introduction

Recently, ubiquitous computing has been adopted in daily-life as the third wave of computerization. Users are almost always connected to computer interfaces in their everyday lives [1]. Accordingly, such user interactions for computer-based applications have evolved in diverse ways, for example, from visual interaction [2] and gesture interaction [3], to voice interaction [4] and motion capture [5]. These interaction ways or methods are collectively referred to as interaction modalities [6–8]. In the context of human-computer interaction (HCI), a modality is a single independent channel of sensory input or output between a computer and user, i.e., communication channel [6]. Inherited from human's senses, these channels are defined as touch, sight, smell, taste, and hearing. The HCI includes but is not limited to those types [9]. These new interaction modalities have allowed input of HCI to go beyond the conventional interfaces: keyboard and mouse [6]. As a result, the user interfaces (UIs) have become multimodal and embedded in more and more products. This has resulted in the boundary between digital and tangible products, which is getting more fused [1], often leading to a digital entity product like an application or a physical object [10]. For these products, it is significant to ensure that users and consumers get a correct and effective user experience during HCI. Otherwise, products are not acceptable even though they are of well-designed and -developed [11]. The focus of product innovation has been shifting from technology to user experience and HCI in that sense [12].

Collina et al. [1] state that a mixed combination of interactions defines the user experience of a product. In HCI, the unpleasant user experience is usually caused by the contradictions between user inputs and computer outputs, i.e., the conflicts between interaction modalities [13]. More precisely, when the configuration and presentation of the mixed interaction modality of input and output in the UI of product are unreasonable, resulting in user operation errors or not getting the desired feedback after the operation, a kind of behavioural contradiction is produced [12]. As examples, the following requirements are considered: "time to perform actions" and "time for messages before they disappear." The display time should ensure the complete reading or comprehension of the message before it disappears, and reducing the time might make this impossible. Thus, the former and latter requirements are correlated with each other. The latter can be negatively affected by reducing the former [12]; UI should provide operational freedom to users to enter any valid data (or click on any screen region) to encourage creativity. At the same time, some kinds of data should be restricted since they might induce operational errors [14].

Although both Nielsen's Heuristic [15] and Usability [8] provided by HCI procedures (Section 2.2) describe this problem, Nielsen's Heuristic only provides an open conceptual direction and lacks a set of solutions to this problem, while for the Usability, some design companies that are forced to follow fast and evolving market law simply do not have enough time and cost to cover enough user types during the design activity process [13].

According to the abovementioned considerations, Theory of Inventive Problem Solving (TRIZ) has been recommended by engineers and designers to support problem solving and the development of innovative solutions, and the resolution of management conflicts [16, 17].

TRIZ is rather a toolset underpinning on a specific base of knowledge, containing a bundle of tools (part of them shortly introduced in Section 2.4), which can be used either, respectively, or in combination with others, according to the specific needs [16–18]. However, it is worth noting that the selection of tools is only guided based on the user's experience at present [17]. Therefore, not all the TRIZ tools receive the same consideration from practitioners [19]. The tools most frequently used by practitioners in this toolset include 40 Inventive Principles, Ideal Final Result, Contradiction Matrix, Trends, and Functional Analysis Model [18].

TRIZ occupies a considerable advantage compared with other methods for problem solving and innovation. Methods such as focus groups and brainstorming have the ability to identify or discover problems and their root causes, but they lack the ability to actually point out solutions to problems [18]. On the other hand, TRIZ is one of the most powerful supports for the fuzzy front-end of the design process, and the related tools can be conveniently integrated into engineering processes to improve creativity in conceptual design [20]. A related example is that a review of integration proposals between TRIZ and FDM is provided by Fiorineschi et al. [17], i.e. the conceptual design approach of the German systematic design. Moreover, TRIZ also supports the design task clarification phase [21].

However, TRIZ and its tools are not sufficient to accomplish the innovation of current products. The increase in product complexity and the focus on user experience nowadays make product innovation consider the HCI aspect [11].

All of this suggests looking for potential synergy between the current HCI algorithm and TRIZ theory.

In such a context, this paper explores various current scientific attempts that take the advantages of HCI and TRIZ explicitly. More precisely, collect and analyze relevant contributions in the literature to understand how to use TRIZ tools in the fuzzy front-end stage of the design process of HCI-related product innovation. Indeed, some literature reviews were conducted on HCI and TRIZ. However, none of them was focused on the combination of HCI and TRIZ. For instance, Batemanazan et al. [22] only selected the usability of the HCI tool and used TRIZ as a reference to discuss how to improve usability. Also, the literature was mostly focused on the integration of TRIZ and other methods, such as the systematic design approach (SDA) [23] and other ideation tools in various fields of applications [20]. Hence, this paper conducts the first comprehensive literature review on the synergy of HCI and TRIZ, with the aim as follows:

(1) Highlighting the research status and trend of the synergy between HCI and TRIZ.
(2) Listing the approaches that support the synergy between HCI and TRIZ, and discussing their observable disadvantages or inadequateness.
(3) Suggesting further research on the existing limitation and problems.

In this paper, a systematic literature review is conducted following the principles presented in Kitchenham et al. [23] and Marshall et al. [24].

The remainder of this work is organized as follows. Section 2 reports an overview of HCI and TRIZ, a possible interaction or integration or synergy between both HCI and TRIZ. Section 3 presents the criteria and requirements for this literature review. Section 4 provides the potential synergy between TRIZ and HCI with the key-contents of the relevant literature. Section 5 discusses the obtained findings, and Section 6 concludes this paper with the summarization.

2. Theoretical Background

2.1. Human-Computer Interaction (HCI). HCI is concerned with methods and tools for interfaces between humans and computers, usability assessment of computer systems [25], and broader human-centric issues for HCI [26]. It is based on the theories about how people perceive information and interact with devices and other peoples that are based on the computer [27], where HCI designers act critical roles between devices and humans [28]. Design knowledge is also brought into the context, including visual hierarchy, color, and typography, by this interaction [29].

The HCI design process is shown in Figure 1. In the first step, user's needs and behaviour are investigated so that designers obtain insights to achieve interactive solutions matched to the user's needs [8, 26]. In the analysis step, the major issues found in the exploration step are analyzed to present the direction to the design step. In this step, it has been suggested to utilize several useful tools, including the goals, operators, methods, and selection rules (GOMS) [30], and touchless hand gesture level model (THGLM) [31]. The primary objective of the design step is to address the issues while bringing practices and factors of usability into the entire design process [26]. Designers develop prototypes while analyzing the performance of the obtained solutions following the guidelines such as Laws of Interaction Design [32, 33] and Nielsen's Heuristics and Norman's Design Principles [15, 34]. The usability of the solution and interaction with users are enhanced by using these guidelines. The prototype step is the integration of physical devices and software. The design violations and effectiveness of the solution are evaluated during the test of user interaction with the solutions [26]. Such a design evaluation method helps designers to find and address undesired problems in the early stages of development. Once the effectiveness and functionality of the prototype are proven, it is implemented and confirmed to be deployed to the market [8, 26].

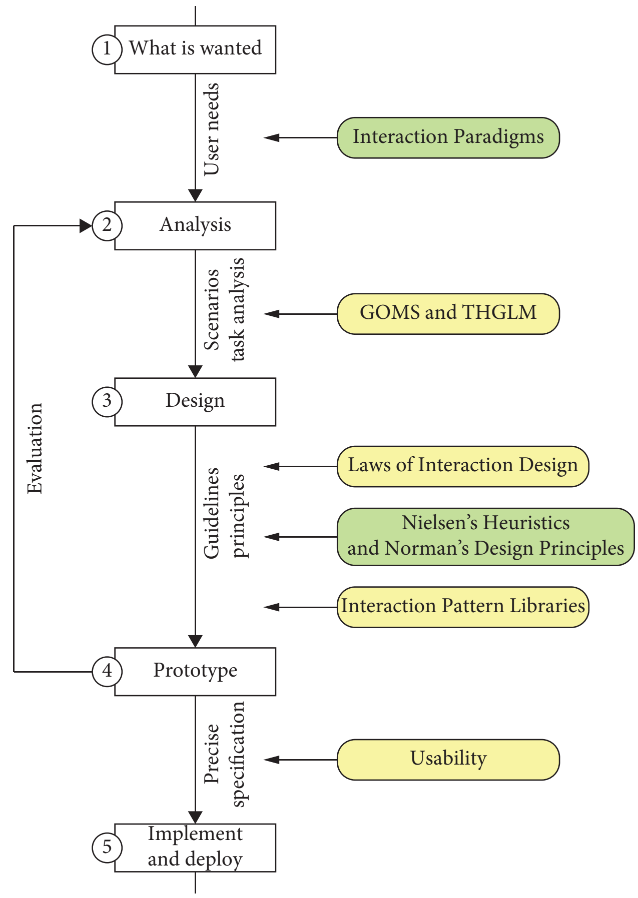

Figure 1: HCI design process [26]. The green boxes represent the tools of HCI knowledge-based concepts, and the yellow boxes represent the tools of HCI description concepts.

2.2. HCI Concepts and Tools. For decades, researchers have been actively studying concepts and tools to exploit efficient and effective HCI. The research studies contain the evaluation of HCI usability, [35, 36], human-centric issues [37], and some law and heuristics to solve interaction problems [38]. A series of specific concepts and tools are contained in the HCI field. Among them, they can be collected into two categories: HCI description concepts, for a formal and usable description of the system under study, and HCI knowledge-based concepts, characterized by items for thinking enhancement and generic problem solving [26, 39]. This paper only introduces methods/tools related to this study.

(i) *Laws of Interaction Design.* Fitts's law, Hick's law, and the Poka-Yoke principle have been contained in this law. Fitts's law is a predictive model, which was mainly employed to model human motion in HCI and ergonomics. Hick's law depicts the time required for a user to make a decision. It is sometimes cited to justify user interface design decisions. Finally, the Poka-Yoke principle states error prevention strategies. The principle prevents, corrects, and draws attention to human errors to eliminate defects of the product [26, 30, 32, 33].

(ii) *Nielsen's Heuristics and Norman's Design Principles.* These heuristics include 10 principles toward UI design, where Nielsen initially evolved and perfected the heuristics by decomposing 249 usability tasks. The principles involve the visualized system status, the match between the system and the actual environment, the consistency and indicators, the user control freedom, etc. [15, 32]. Norman's Design Principles: they suggest designers what to provide and what to avoid during the development of a system interface. Among them, there are visibility, feedback, natural mapping, constraints, and design for error [34].

(iii) *Usability.* Usability is indispensable for most products. Several significant usability methods/tools have been extracted and divided into three categories: Usability Testing, Usability Inquiry, and Usability Inspection [15, 33, 36, 38]. Usability Testing selects typical users to let them use the product to deal with tasks and then assesses the design intuitiveness of the product. Usability Inquiry assesses the product based on users' feelings when they are using the product, where users are observed and inquired to reply to the related questions. Finally, the experts inspect the usability of product analytically in Usability Inspection [22, 40]. Usability contributes to the foundation of the user-centered design (UCD) approach [8].

(iv) *Interaction Pattern Libraries.* Interaction design patterns are an instrument to depict solutions to general usability problems in a particular context

[41], while the Interaction Pattern Libraries are a list of all the interaction patterns [42].

(v) *Interaction Paradigms.* This concept refers to a specific philosophy or way of thinking for HCI [38]. Interaction designers are confronted towards the questions that need self-thinking in design process, in order to lead the future design for interfaces between humans and computers. For instance, these paradigms include technology integration, real-time computing, wearable interaction, mixed reality, artificial intelligence, etc. [8, 38].

(vi) *Goals, Operators, Methods, and Selection Rules (GOMS) and Touchless Hand Gesture Level Model (THGLM).* In HCI, GOMS is a specialized human information processor model for HCI observation that describes a user's cognitive structure on goals, operators, methods, and selection rules [43]. The THGLM is a model based on the keystroke-level model (KLM) [30], and gesture units and performance time for hand gesture user interfaces can be estimated using THGLM [31].

2.3. Theory of Inventive Problem Solving (TRIZ). TRIZ was proposed by Altshuller in 1946 [44].

The TRIZ is used to guide in solving problems, preventing the solution from being randomly explored [36, 39]. In TRIZ, the specific problem is elevated to a higher level of abstraction before being solved. The specific problem must be first identified and described precisely. Then, the particular problem is converted into one of the TRIZ generic problem types found in TRIZ 39-Parameter, under the form of technical or physical contradiction. Next, some standard solutions may be found through the TRIZ matrix for the particular problem by examining all the standard solutions provided by TRIZ for that type of generic problem (e.g., 40 Inventive Principles for solving contradictions). After that, the standard solutions are evaluated against the technological evolution trends to further enhance the goodness of the standard solutions. Finally, the problem-solvers exploit their experience and expertise in deriving and customizing a specific solution that is practical to the particular problem [44–46]. Figure 2 illustrates the TRIZ problem-solving framework steps, suggested by the Kamarudin [47].

Moreover, several significant branches of TRIZ evolution and/or alternatives have been developed through the improvement of the limitations of the classical TRIZ by researchers during the years such as SIT [48], USIT [49], and CROST [45]. However, a detailed description of all these contributions is beyond the scope of this paper. Nevertheless, OTSM-TRIZ [50] and TOP-TRIZ [51] have to be mentioned in the development of TRIZ. The "OTSM" is a Russian acronym of "General Theory of Powerful Thinking," and "TOP" stands for "Tool-Object-Product." They aim to provide better support for solving complex problems [17]. Complexity is hereby understood as a situation where there is a chain of contradictions exist in the problem being analyzed [16].

Eventually, the important principles of the modern TRIZ theory are mainly reflected in three aspects: (1) the core technologies should be developed to follow the expansion of objective laws, whether it is a simple or complex technical system. It is an objective rule and pattern for the technical system. (2) The development of technology is promoted by the solution of technical problems and conflict. (3) The ideal state of a technical system is to achieve the complete functions with the least resources possible [44, 46].

2.4. TRIZ Concepts and Tools. Savransky [46] states that the system composition framework of TRIZ can also be divided into three parts. There are the basic theoretical framework, problem analysis framework, and problem-solving framework of TRIZ, respectively. In the basic theoretical framework, the evolution of technological systems and the Ideal Final Result (IFR) still are the core point of view. In the problem analysis framework, TRIZ offers analysis tools Function Analysis Model (FAM), 39-Parameters (39-P), Contradiction, and ARIZ. TRIZ's problem-solving framework includes 40 Inventive Principles (40-IP), Effects Database, 76 Standard Solution, Separation Principles, etc. [44, 47]. This paper only extracts the TRIZ tools related to this study for introduction.

(i) *Ideal Final Result (IFR).* A psychological index, IFR, allows obtaining the optimal solution of complicated problems without considering constraints. In this measure, ideality is defined as a kind of virtual goal by the ratio between useful/positive and harmful/negative functions of the system in TRIZ. The perfect system, IFR, has the highest ideality, which provides all the benefits but no negative experiences to the user. IFR is an unachievable utopia system, but it could provide rarely searched directions in the exploration [20, 45, 47].

(ii) *Functional Analysis Model (FAM) and Trimming.* FAM splits the product system and highlights the relationship between the function of components in a product system. In order to avoid underuse and conflicts of components in each system, different function values have been installed in the interaction between the components, useful/sufficient or useful/harmful [44, 52]. The Trimming concept exploits the functional description of the product, because it increases the value of the product by eliminating components and suggesting how to transfer their subfunctions to the untrimmed components. The goal is of course to keep the main function of the system unaltered. The FAM and Trimming are helpful in defining the problem and improving the ideality of the system [44, 53].

(iii) *Contradiction and the Contradiction Matrix.* In TRIZ, the problem is possibly stated in terms of contradictions. A contradiction arises in the system when two objectives, required to achieve the goal of the system, are conflicted. In TRIZ, the problems have at least one contradiction that should be

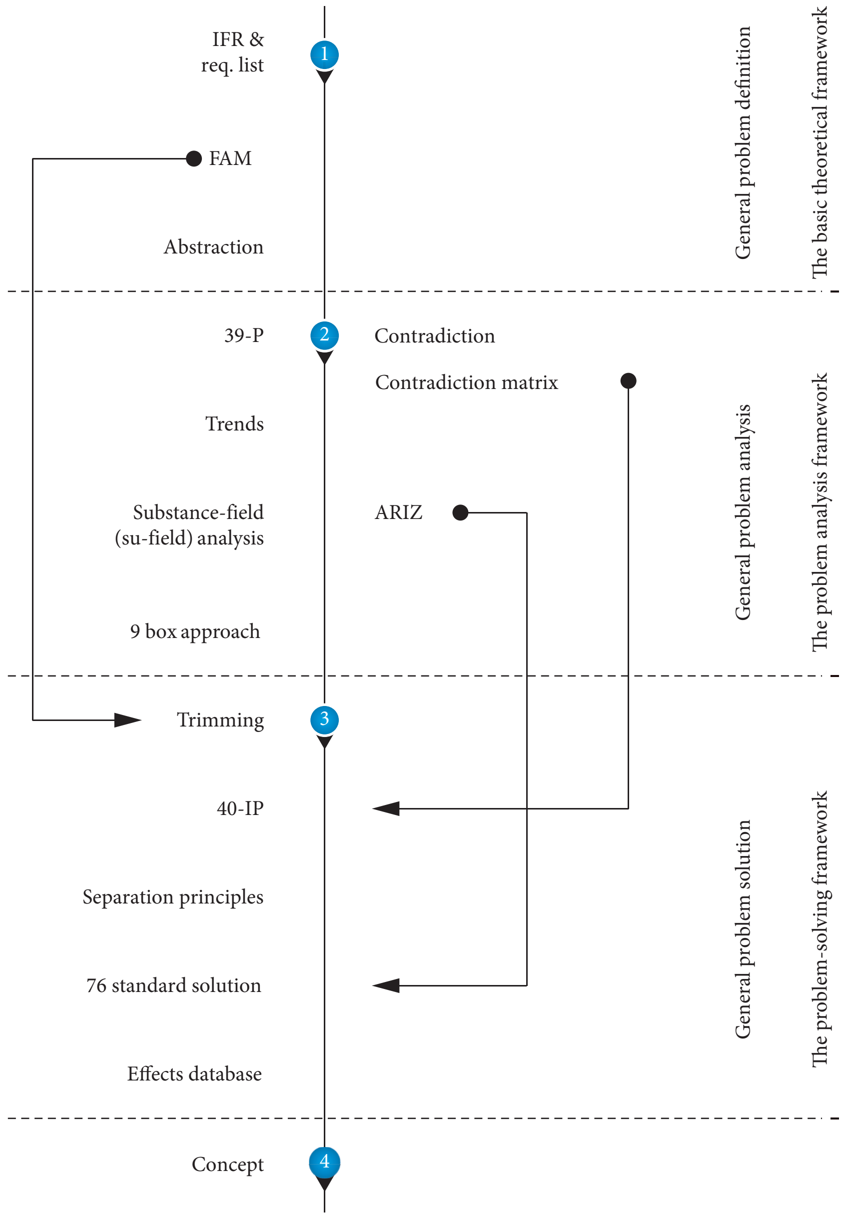

Figure 2: TRIZ problem-solving framework steps (adapted from [47]. The FAM is included in the problem analysis framework.

entirely or partially addressed by an inventive solution, while the Contradiction Matrix is a matrix composed of 39-P. These parameters are arranged vertically and horizontally inside the TRIZ matrix to influence each other. It is used to indicate the invention principles and address technical contradictions [44–47].

(iv) *40 Inventive Principles (40-IP).* Altshuller constructed the list of 40-IP by analyzing a large number of patents. These principles are especially significant for resolving conflicts or contradictions between components. The TRIZ practitioners exploit the 40-IP to come up with useful concepts of inventive solutions. A recommended modification to the system is derived from each solution for alleviating contradictions [44–47].

(v) *Trends.*The trends are the results of system evolution. There have been found various trends of evolution in the literature. Among them, there are eight dominant trends [52]. According to Altshuller's works, the evolution ends up like S-curve when the system follows such trends. Accordingly, the trend type of system can be determined by analyzing the current and past states of the system. Based on this, the evolution of the system in the future can be estimated [17, 45].

(vi) *Effects Database.* This database consists of about 2,500 concepts extracted from scientific and engineering knowledge and applied in solving a problem [20]. The concepts are categorized by the functions that they provide.

(vii) *Multiscreen (9-BOX) Approach.* This is the simplest and most powerful TRIZ concept, also known as time and space interface. This concept is figured as a 9×9 square matrix where the columns describe three different times, past, present, and future, while the rows contain three different levels of system description: supersystem, system, and subsystem. This method is used in system analysis, to define the system environment, supersystem, and all the system details of subsystems, taking a look to the past, considering the present, and trying to foresee the future [45, 46].

2.5. Comparison of HCI and TRIZ. HCI and TRIZ are compared in terms of both analogies and differences to find contact points exploited in this section. The analogies are summarized in Table 1.

"Nielsen's Heuristics and Norman's Design Principles" can be incorporated into a relationship with "40-IP." The optimal design can be found through those guidelines. Furthermore, they can be applied to different problems and contexts. "Trends" are also somewhat correlated with "Laws of Interaction Design" since interaction designers often use the laws of interaction design when imaging the future developments. Another correspondence can be identified between "Usability" and "IFR." This correspondence is intended to design products that are as usable as possible, i.e., products that can be used under ideal conditions. The "GOMS and THGLM" are also related to "FAM and Trimming." Designers use "GOMS and THGLM" to calculate the time of user accepting information to develop HCI. This is similar to using the "FAM and Trimming" to adjust the function between components. In addition, an analogy can be identified between "Interaction Pattern Libraries" and "Effects Database." They all collect and classify the verified effects, functions, experience, and more into a list. Finally, an analogy can be identified between "Interaction Paradigms" and the "9-Box Approach." They allow designers to analyze the product according to their temporal and spatial statuses. The temporal status can be present, past, and future, while spatial status can be itself, subsystems/subfunctions, and environment.

It is crucial to analyze the differences between the HCI and TRIZ so that a way to compensate for the weakness of the method can be investigated. For instance, a strong correlation between any HCI item and "TRIZ Contradiction" was not found. Only a weak correlation was found between the mixed interaction modalities of UI and "TRIZ Contradiction"; that is, there are conflicts of mixed interaction modalities in the UI of the product, and the contradictions may be found.

The differences between HCI and TRIZ are summarized in Table 2. First, well-structured approaches are employed in TRIZ, while a loosely structured strategy is used in HCI for the problem solving. The different aims highlight the lack of systematic strategy. Second, HCI focuses on the interaction aspects and users' needs, while TRIZ focuses on functionality and technical aspects of problems. Third, real context is emphasized in HCI, while abstraction is emphasized in TRIZ theory and concepts. Last, the innovation process is conducted in terms of "why" in HCI, while in terms of "what" and "how" in TRIZ. Since the experience and skill of the team members play a crucial role in the innovation process of HCI, the reasoning results of HCI are more focused on the aspects of "why," but often solutions are not suggested. On the other hand, TRIZ suggests the aspects of "what" and "how" and thus can describe real solutions due to its structured strategy [11].

Table 1: Similarities of analogies between HCI and TRIZ.

HCI	TRIZ
Nielsen's Heuristics and Norman's Design Principles	40 Inventive Principles (40-IP)
Laws of Interaction Design	Trends
Usability	Ideal Final Result (IFR)
GOMS and THGLM	Functional Analysis Model (FAM) and Trimming
Interaction Pattern Libraries	Effects Database
Interaction Paradigms	Multiscreen (9-Box) Approach

Table 2: Differences between HCI and TRIZ (adapted from [11].

HCI	TRIZ
Loosely structured approaches	Highly structured approach
Focus on interaction aspects and users' needs	Focus on functionality and technical issues
Emphasize the real context	Emphasize abstraction
Describe "why"	Describe "what" and "how" (in early stage, TRIZ describe "why")

3. Materials and Methods

The form and extent of the literature can be identified on a particular subject by a systematic literature review [54, 55]. Systematic literature reviews, mapping studies, and content analysis can be used in finding evidence via a literature review [56]. In this context, the main objective of a systematic review is to identify, evaluate, and interpret the relevant research to the research questions. The second objective is to collect evidence to state the current study in the target area [57]. This paper is organized using the main activities proposed by Kitchenham et al [23] and Marshall et al [24]: planning, conducting, and reporting the study.

3.1. Review Planning. In the processes of review and planning, the details about the literature review are determined, including sections the overall protocol and objectives. Relevant aspects of the review are described in the following.

3.2. Research Questions (RQs)

(i) RQ1: what approaches have been proposed to support the synergy between HCI and TRIZ?

(ii) RQ2: what HCI and TRIZ tools are applied in these approaches?
(iii) RQ3: which tool is used most frequently in HCI and TRIZ?
(iv) RQ4: which is the most common type of research method and outcome?
(v) RQ5: which topics should be addressed?
(vi) RQ6: what are the trends in the synergy between HCI and TRIZ?
(vii) RQ7: what are the future challenges of the synergy between HCI and TRIZ?

Based on the RQs, the Population, Intervention, Comparison, Outcomes, and Context (PICOC) method is used. It proposed by Kitchenham et al. [23] to determine the scope of the literature review:

(i) *Population (P).* The investigated groups: HCI and TRIZ.
(ii) *Intervention (I).* The issues/aspects of interest are specified: suggestions or analysis of the synergy between HCI and TRIZ.
(iii) *Comparison (C).* The comparison target: suggestions or analysis of the synergy between other design theories and HCI or TRIZ.
(iv) *Outcomes (O).* The expected results by the intervention: the real-world experiences and proposals of the synergy between HCI and TRIZ.
(v) *Context (C).* The environmental conditions: the environments related to HCI and TRIZ (e.g., industry and academia).

3.3. Inclusion Criteria (IC) and Exclusion Criteria (EC). In order to answers the RQs, the following criteria are adopted. In this paper, five each ICs and ECs are used, which are defined as follows:

(i) IC1: the paper has described the synergy of HCI and TRIZ or approaches based on the synergy of HCI and TRIZ,
(ii) IC2: the paper has clearly described which HCI and TRIZ tools were used, the process of synergy, and what problems were solved,
(iii) IC3: the paper has evaluated the proposed approaches and presented the evaluation results,
(iv) IC4: the paper was written in English, published after 2010, and
(v) IC5: the paper was published in peer-reviewed journals, books, conferences, or workshops.

The opposite criteria for each IC are established EC. Thus, any paper that does not meet the IC is excluded.

3.4. Query String. Search terms were set as simple as possible to ensure enough research studies being searched, whereas a wide diversity is taken into account in the databases. The major terms were identified from the RQs, the PICOC, and the possible alternative synonyms and spellings. The obtained queries using logical searching operator based on the identified terms were as follows: (“Human-computer interaction” OR “Human computer interaction” OR “HCI”) OR (“Interaction Design” OR “IXD” or “ID”) AND (“TRIZ” OR “Theory of Inventive Problem Solving”). The relevant papers were searched in various databases that cover the high impact of publications, guaranteeing the research quality, which includes Web of Science, Engineering Village, Elsevier Science Direct, Scopus, IEEE Xplore, ACM Digital Library, and Springer Link.

3.5. Review Process. The searched papers were passed the following review process to select relevant papers that are used in the systematic literature review:

(1) Query to the databases (identification): 438 papers were retrieved (1 from Web of Science, 9 from Engineering Village, 218 from Elsevier Science Direct, 7 from Scopus, 9 from IEEE Xplore, 12 from ACM Digital Library, and 182 from Springer Link).
(2) Duplicated studies were removed (screening): 423.
(3) Review by title, abstract, and keywords (eligibility): 40 (9% of the papers retrieved). Additional 6 papers are included via the review of primary references.
(4) Selected papers after full reading (included): 17 (3.82% of the retrieved papers and 42.5% of the read papers). These papers were selected based on their content only. Bibliometric information, such as citations and the published journal, was not considered.

The flowchart of the systematic literature review is shown in Figure 3, which follows the PRISMA statement [58].

3.6. Information Extraction. In the next step of the protocol elaboration, the type of extracted data from the articles is defined. Also, the method to extract the data is determined. The textual content is used in analyzing the articles.

In this paper, the retrieved research papers were classified by using the extracted information according to the criteria used in previous research studies. The content-based criteria for the classification followed the research contribution type of HCI proposed by Wobbrock and Kientz [59].

The extracted information is summarized as follows:

(i) Publication year
(ii) Publication type (journal/conference)
(iii) Authors
(iv) Publication title
(v) Research field
(vi) HCI/TRIZ tools (Laws of Interaction Design, Usability, Interaction Paradigms, Contradiction, 40-IP, IFR, etc.)

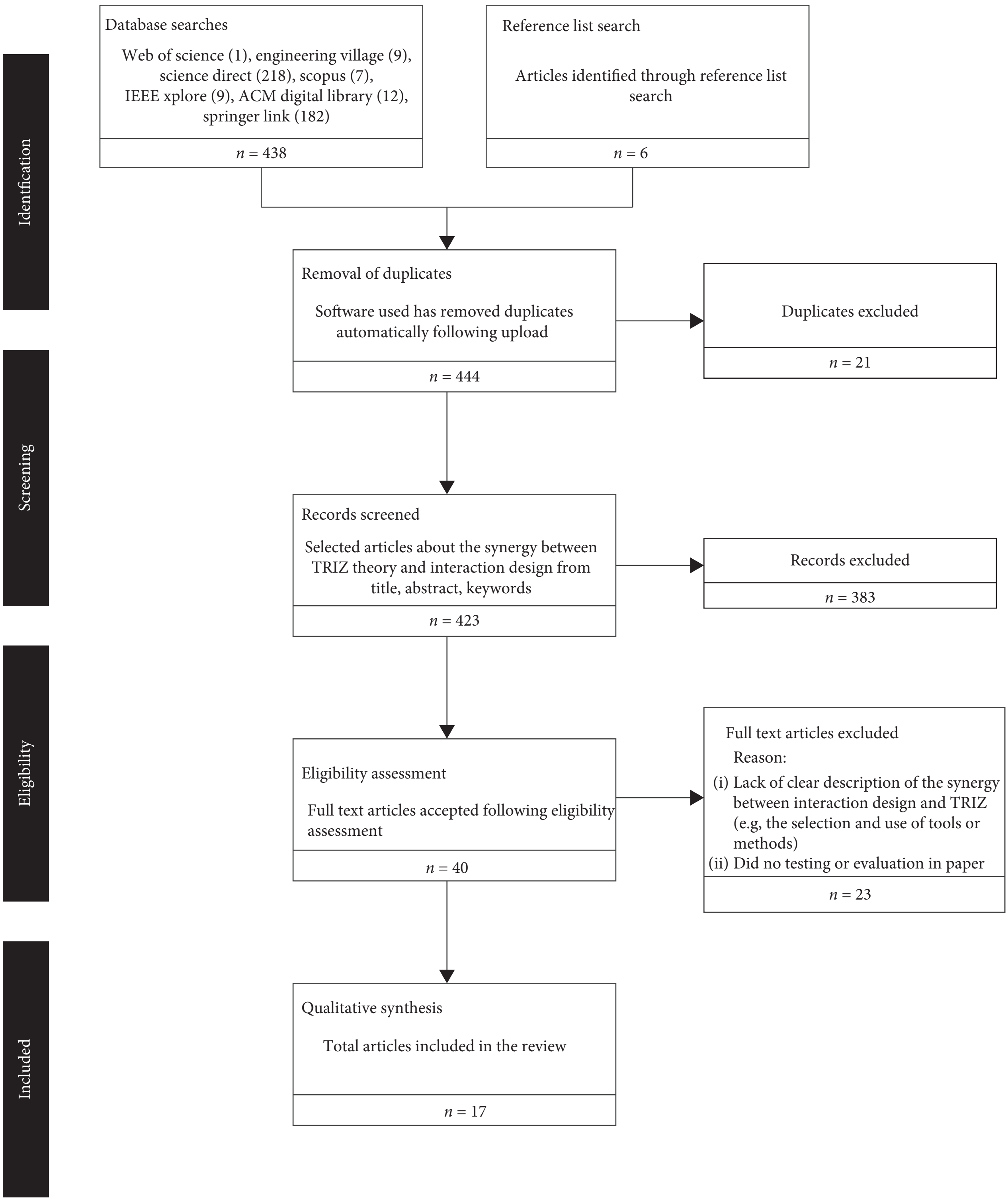

Figure 3: Steps and results of paper review process.

(vii) Research methods (statistical analysis, literature review, survey, case studies, experimental design, etc.)

(viii) Outcome type (model/framework, design recommendation, method/methodology, tool/toolkit, metric/measurement, system prototype, workflow, opinion, practitioner guidelines, etc.)

4. Results

In this section, firstly, the comparison of the proportion of the search result categories is then presented in the relevant data to analyze RQ3, RQ4, and RQ5 in the protocol.

Secondly, the process of extracting papers contains the approaches of synergy between HCI and TRIZ, a total of 10 out of 17 publications. These 10 approaches are reviewed to examine the commonalities between them. The analysis approaches are compared with the definitions of the three main design phases presented by Michailidou et al. [60] to explore RQ1 and RQ2 in the protocol(Table 3).

4.1. Search Results. The analysis was conducted following the protocol specification. Finally, 17 publications were found. Table 4 shows the number of publications found in each database. The number of publications found in each database is not impressive, and most databases only publish one to three works on the subject. This suggests that the field of synergy between HCI and TRIZ has not been well integrated or has not been developed to apply in other fields since there exists no database that is used in a meaningful number of publications.

Among them, the largest number of papers (1 journal paper and 6 conference papers, 41.17%) is published by Springer Link, followed by Elsevier Science Direct (2 journal papers and 1 conference paper, 17.64%), and by Engineering Village (1 journal paper and 1 conference paper, 11.67%).

Regarding publication types, conference papers of 6 or fewer pages were classified as short papers [57]. The result highlights that there are 12 conference papers (70.58%) out of 17 papers, but there are no short papers, indicating that the field has already matured in some aspects of the field. However, the overall system integration of HCI and TRIZ is still in development.

In the temporal aspect, the sample included articles published since 2010 (Figure 4).

The number of publications has shown a steady trend. It shows that studies in this field have always been supported, but not numerically evolved with time, and therefore shows interest in this topic may not increase in recent years unless stimulated by external factors.

In order to understand the process of the synergy between HCI and TRIZ, and determine the research background and field, analyze the HCI and TRIZ tools used in these publications and the frequency of using these tools, which is the research strategy of this study. As mentioned above, the cumulated numbers of times for utilizing different kinds of HCI and TRIZ tools in 17 publications are presented in Table 5.

The results indicated that "Usability" (9 papers, 52.94%) and "Laws of Interaction Design" (4 papers, 23.52%) were applied more in the HCI tools while "Contradiction" (6 papers, 35.29%) and "40-IP" (5 papers, 29.41%) are utilized more in TRIZ tools. In addition, the "Interaction Paradigms" and "Nielsen's Heuristics and Norman's Design Principles" in HCI, as well as the "IFR" in TRIZ, have the same data with 1 paper (5.88%), respectively.

In Table 6, the contributions are analyzed in more detail, showing the most commonly used research methods and the type of outcome. In research methods, case studies (7 papers, 41.17%) are the most employed, followed by literature review (4 papers, 23.52%) and experimental design (3 papers, 17.64%). In the type of outcome, the most common types of results are method/methodology (6 papers, 35.29%), followed by model/framework (3 papers, 17.64%), and design recommendation (2 papers, 11.76%). There are the same data (1 paper, 5.88%) in tool/toolkit, metric/measurement, opinion, workflow, system prototype, and practitioner guidelines, respectively.

Then, further analysis was carried out for the research context and domain. Table 7 presents results concerning the domain. A noticeable percentage of research was focused on the "HCI" area (10 papers, 58.82%). It indicates the significance of that domain as a motivation for user experience. Other areas are "engineering" (5 papers, 29.41%), "computer science" (1 paper, 5.88%), and "health and safety" (1 paper, 5.88%), respectively.

4.2. Review of Synergies between HCI and TRIZ Literature Contribution

4.2.1. The Design with Intent (DWI) Method of Lockton et al. In the design with intent (DWI) process [61], the system is modified to guide user's behaviour towards the target behaviour. The DWI can be applied to a product, service, and environmental system that is affected by user's behaviour. It is also applicable to the system where altering the way is strategically desirable. As a suggestion tool, the method inspires design solution with examples that can be applied to the target behaviours. The target behaviours were obtained by evaluating examples from different disciplines, and they were inspired by the TRIZ effect database. The DWI can assist designers to explore responses to a brief by taking the benefic from others' work on analogues problems, even though the domain expertise, insight, and creativity of professionals cannot be replaced by the DWI.

4.2.2. The Innovation-Oriented Interaction Design (ID) Approach of Filippi and Barattin. Filippi and Barattin [39] propose a new approach called innovation-oriented interaction design (ID). This method allows using both a new analytical method that includes only the ID items and synergy between the systematic approach of TRIZ and the unstructured ID and focuses on the ideation and concept generation stage. A significant part of the method is the utilization of the ID-oriented IFR concept. In comparison with a "classic-style" ID process, where the phases are (1) design research, (2) analysis and concept generation, (3) alternative evaluation, (4) prototyping, and (5) implementation, (6) testing, the innovation-oriented ID process is based on a more structured idea and concept generation phase (Figure 5), where there are some new phases: specific problem description, and innovation-oriented ID generic problem description, which represent the typical phases of the TRIZ process for the functional description of the system. Moreover, the proposed method splits the old alternative design and evaluation phase into two new phases: innovation-oriented ID generic solution generation and specific solution generation, for a more systematic

Table 3: Approaches of the synergy of HCI and TRIZ supported in the considered proposals. Grouped by the three main design phases proposed by Michailidou et al., i.e., analysis (A), creation (C), and evaluation (E) as well as integration strategy by authors, i.e., merge-type (M), combine-type (C), and suggest-type (S).

Approaches	HCI				TRIZ					Phases (analysis, creation, and evaluation)	Type (merge, combine, and suggest)
	Interaction Pattern Libraries	Laws of Interaction Design	Usability	Interaction Paradigms	Contradiction Matrix	Inventive Principles	Ideal Final Result (IFR)	Trends	Effects Database		
Design with intent (DWI) method [61]		✓							✓	C	S
Innovation-oriented ID approach [39]				✓			✓			A,C,E	M
Interaction trends of evolution (ITRE) [62]			✓					✓		A	C
User experience principles [63]	✓					✓				C	S
Interaction design guidelines (IDGLs) framework [12]			✓		✓					A, C	M
Multimodal interaction framework [64]			✓			✓				A, C	C
Interaction design-integrated method (IDIM) [65]			✓			✓				A,C,E	M
Integrating user information method [13]		✓			✓					A	C
Human-centered innovation process method [66]		✓			✓					C	C
Ergonomic product design model [67]			✓					✓		A, C	C

Table 4: The numbers of published journal and conference papers in each source.

Source	Journal	Conference	#Pub. (%)
Web of Science	1	0	1 (5.88%)
Engineering Village	1	1	2 (11.67%)
Elsevier Science Direct	2	1	3 (17.64%)
Scopus	0	1	1 (5.88%)
IEEE Xplore	0	2	2 (11.67%)
ACM Digital Library	0	1	1 (5.88%)
Springer Link	1	6	7 (41.17%)
Total	5	12	17

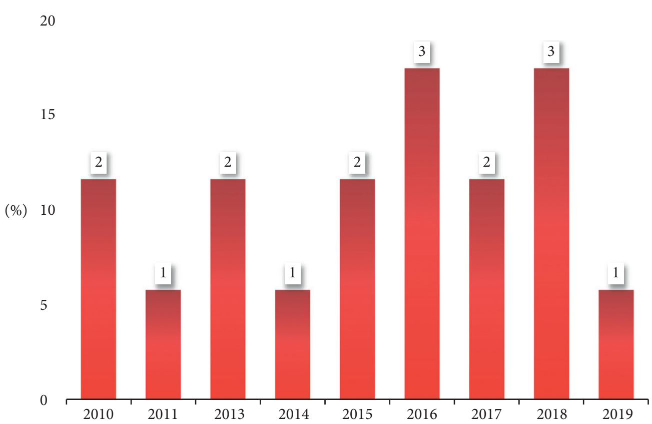

Figure 4: Publications chosen for this research per year.

Table 5: The cumulative number of "research methods" and "outcome types" in chosen publications.

Methods and tools	#Pub. (%)
HCI	
Interaction Pattern Libraries	2 (11.76%)
Laws of Interaction Design	4 (23.52%)
Usability	9 (52.94%)
Interaction Paradigms	1 (5.88%)
Nielsen's Heuristics and Norman's Design Principles	1 (5.88%)
TRIZ	
Effects Database	3 (17.64%)
Trends	2 (11.76%)
Contradiction	6 (35.29%)
Ideal Final Result (IFR)	1 (5.88%)
40 Inventive Principles (40-IP)	5 (29.41%)

exploration of the solution space during the ID problem-solving activities.

4.2.3. The Interaction Trends of Evolution (ITRE) of Filippi and Barattin. After the innovation-oriented ID approach, Filippi and Barattin [62] propose a new approach called interaction trends of evolution (ITRE). The information on evolution for several aspects of the user-product interaction is gathered so that the development direction is anticipated for the product. The same process exploited in highlighting trends is used based on the TRIZ theory. The results are composed of 9 interaction trends (functional contemporaneity, long-term memory, short-term memory, self-update, self-government, intermediaries, feedback, help, and context span). Each of them shows examples that help in comprehending their meaning and their possible exploitation as design tools.

Table 6: The cumulative numbers of utilization of HCI and TRIZ tools in publications.

Variables	#Pub. (%)
Research method	
Case studies	7 (41.17%)
Experimental design	3 (17.64%)
Survey	2 (11.76%)
Literature review	4 (23.52%)
Statistical analysis	1 (5.88%)
Type of outcome	
Tool/toolkit	1 (5.88%)
Model/framework	3 (17.64%)
Method/methodology	6 (35.29%)
Metric/measurement	1 (5.88%)
Design recommendation	2 (11.76%)
Opinion	1 (5.88%)
Workflow	1 (5.88%)
System prototype	1 (5.88%)
Practitioner guidelines	1 (5.88%)

Table 7: The cumulative numbers of "Research Domains" in chosen publications.

Domain	#Pub. (%)
Health and safety	1 (5.88%)
Human-computer interaction (HCI)	10 (58.82%)
Engineering	5 (29.41%)
Computer science	1 (5.88%)

4.2.4. The Use of "40 Innovation Principles (40-IP)" Suggested by Von Saucken et al. Based on the TRIZ 40-IP, Von Saucken et al. [63] collected and analyzed product reviews and experience descriptions. These reviews were classified by the customer experience interaction model (CEIM) elements [68]. Von Saucken et al. derived user experience principles from them. Through the principles and corresponding examples, useful recommendations are provided to improve user experience aspects [60].

4.2.5. The Interaction Design Guidelines (IDGLs) Framework Created by Filippi and Barattin. Based on the experience accumulated in ID approach and ITRE, Filippi and Barattin [12] created interaction design guidelines (IDGLs). In IDGL, an interaction design framework and guidelines are semi-automatically generated to develop innovative interactive products. It consists of synergically operating submodules linked to each other, based on classic design structures, as the house of quality coming from quality function deployment (QFD) [69]. The process of IDGL adoption is as follows (Figure 6): first, features of the product are described, as the final users' characteristics. Then, the user's needs and expectations are obtained through the generated

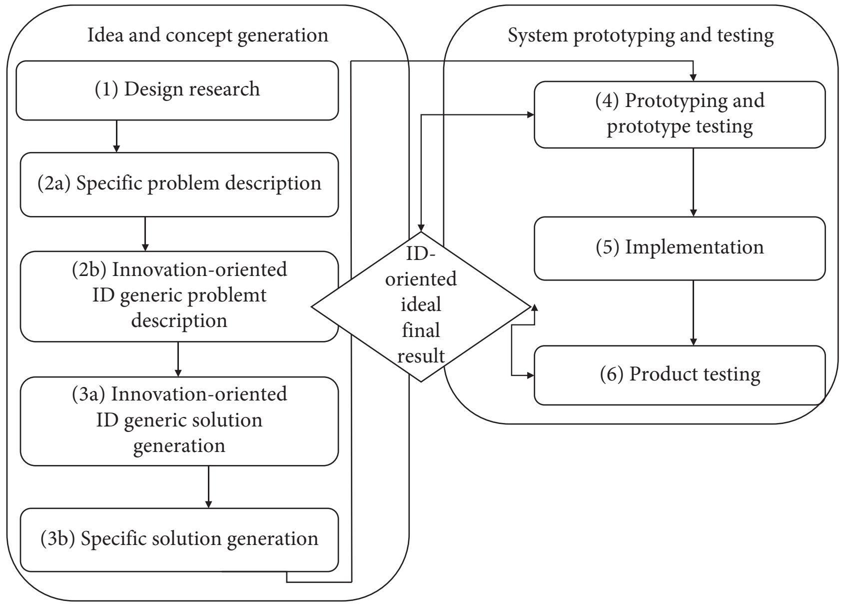

Figure 5: The process of the innovation-oriented ID approach [39].

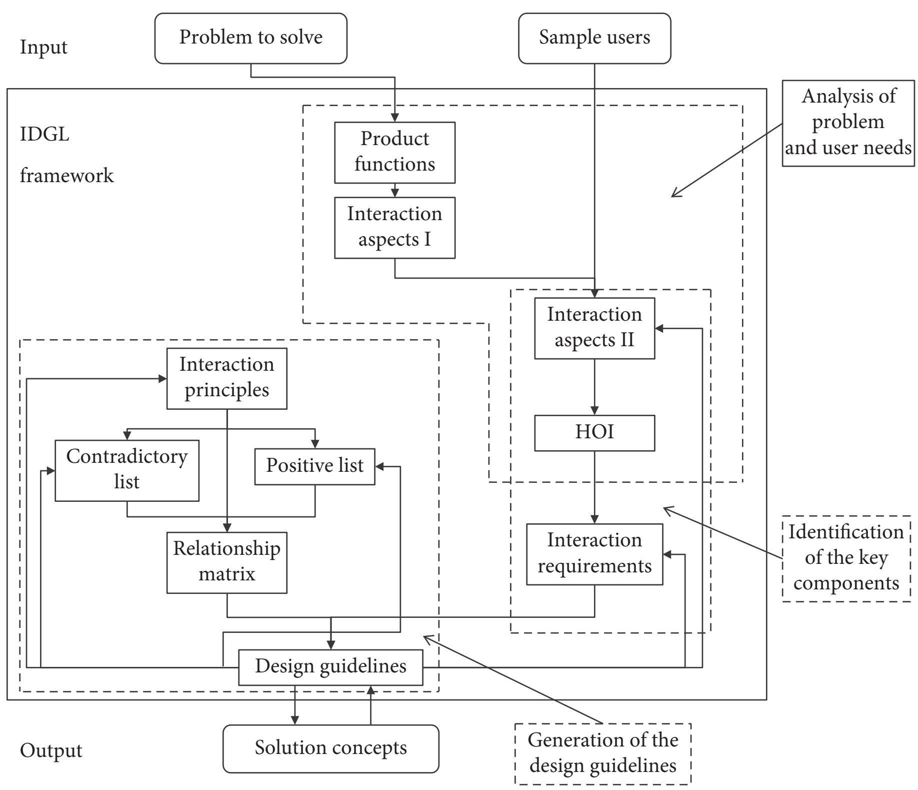

Figure 6: The IDGL framework [12].

questionnaire. The house of interaction is filled with all the information, which is the primary data structure of the IDGL derived from the house of quality (HOQ). The interaction requirements are highlighted, and design guidelines are generated accordingly. In doing so, tools and methods can be extracted directly from TRIZ theory and modified and customized according to the requirements of interaction design.

4.2.6. The Interaction Design Integrated Method (IDIM) of Filippi and Barattin. Filippi and Barattin [65] embedded the usability evaluation multimethod (UEMM) in IDGL and ITRE. The input data for UEMM adoption activities are the application fields, including strategies, the features of the product, and available design resources. The goal is that helping the designer to select the best evaluation methods [62]. Therefore, they created a new interaction design-integrated method (IDIM), where usable and innovative design solutions for interaction are generated in the first part of the product development process, from gathering user needs to validated design solutions. Among them, the ITRE focused on analysis; IDGL focused on creation; UEMM focused on evaluation. In order to avoid redundancy and optimize the effectiveness, the three methods are integrated. In addition, the goal of this method is to extend the Function-Behaviour-Structure (FBS) framework [70] to the HCI field.

4.2.7. The Use of "User Information" Proposed by Sun et al. According to Sun et al. [13], contradictions between the user and the product performance sometimes induce the modification of design after prototyping. Such contradictions are caused mainly when the sociotechnical factors are not considered into the design. A user manual is created for the product for instructing the user how the product operates after prototyping. Sun et al. proposed to generate the user manual based on behavioural design approach (BDA) [71], so that the interaction between behaviours of user and product is analyzed to guide designers in the early design phase. In such a way, the potential contradictions can be found before the prototyping, avoiding unnecessary efforts for a design modification. Consequently, the required cost and time can be reduced, improving the performance of the product.

4.2.8. The Multimodal Interaction Framework Developed by Mocan et al. In the multimodal interaction framework (Figure 7) developed by Mocan et al. [64], the needs for the process, objective functions, operators' requirements, and the best combination of the multimodal interface inputs are identified when designing multimodal systems of industrial robots. First, the analytical hierarchy process (AHP) tools [72] define and rank the requirements that include operator requirements, process, and robotic system needs. Also, target functionalities are defined using the QFD according to the intuitive programming needs. They are deployed against the set of requirements. Second, the vectors of innovation are formulated by TRIZ for each negative correlation between target functionalities and challenging targets. The design specifications are constructed for the multimodal interface. Finally, the concept solutions for multimodal interaction are generated and evaluated and Pugh's concept selection method (PUGH) [73] can be used to fulfill this step. In this framework, the flexibility is provided by real-time interaction so that captured intent is closer to the user's actual intention.

4.2.9. The Human-Centered Innovation Process Method of Lee. Lee [66] describes a human-centered innovation process method with simplified TRIZ. The process of this method is as follows: first, it requires translating the contradictions and the causes of contradictions into the design purposes in the design method and then judges whether the conflict of design purpose is a technical contradiction or a physical contradiction. Next, use the separation principle to generate a solution for each design purpose, respectively. Finally, pour the IFR to merge the solutions.

4.2.10. The Ergonomic Product Design Model of Zhang and Joines. Zhang and Joines [67] proposed the integration of multidisciplinary models of UCD and TRIZ for ergonomic product design (Figure 8). The integrated model is conducted in the following three steps. First, thorough user needs are identified by using three ergonomic need dimensions integrated with UCD. Next, the relative importance of user needs is rated with a 5-point Likert scale [74]. Cronbach's coefficient alpha statistic [75] is used to test the internal consistency and reliability of user needs. Then, the final scores and priority of user needs are constructed. Second, the 8 patterns of evolution of TRIZ are selected to generate a design idea, with the priority of user needs. Finally, an alternative design is created by using the design idea together with the ergonomic design principles.

5. Discussion

In this section, the trend (RQ6) and research status of the synergy between HCI and TRIZ are discussed, followed by considerations regarding recommendations for future work (RQ7) and the limitations of this study.

5.1. About Trend in the Synergy between HCI and TRIZ. From the analysis of the type and number of publications in the synergy between HCI and TRIZ, there is a steady trend in publications, and therefore, we deduced that interest in this topic may not increase in recent years unless stimulated by external factors.

In these publications, "Usability" and "Laws of Interaction Design" are the most used tools in HCI; "Contradiction" and "40-IP" are the most commonly used tools in TRIZ. In addition, case studies, literature reviews, and experimental design are more widely employed in the articles of the area.

This paper showed that the area of the synergy between HCI and TRIZ is not thoroughly studied, since there is not one database with a significant number of publications. In addition, the research of these publications in the field of HCI is noticeably concentrated.

These results seem to indicate that the synergy between HCI and TRIZ has already matured in some aspects of the field, but the overall system integration of HCI and TRIZ still needs improvement. In addition, most models, frameworks, and design recommendations are only applicable to the field of HCI and have not been developed for other fields. Therefore, there is still room for research on the synergy between HCI and TRIZ.

5.2. About the Current Link between HCI and TRIZ. By analyzing literature contributions, several relevant research studies that tried to describe the objectives and frontiers of the synergy between HCI and TRIZ have been found. The

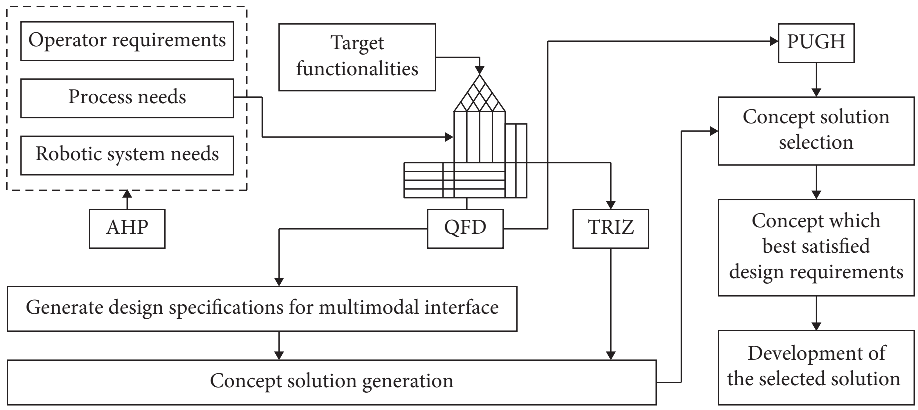

Figure 7: The multimodal interaction framework [64].

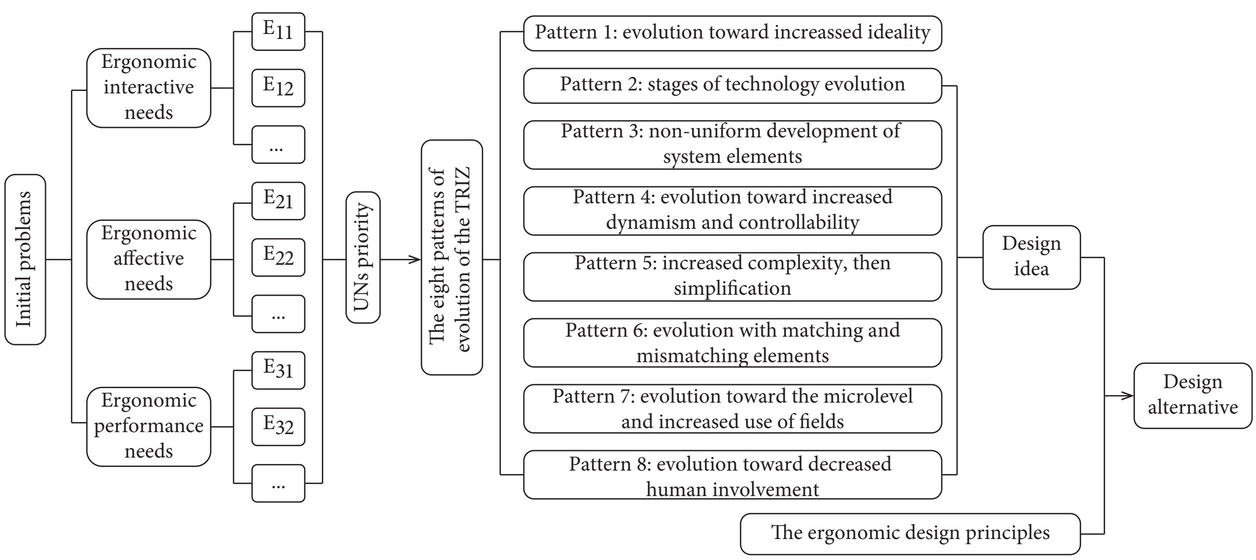

Figure 8: The ergonomic product design model [67].

problem, concepts, and related approaches to the subject were introduced by them(Table 8).

However, most of the research contributions give only short introductions to HCI and TRIZ and their related tools and extract some tools or concepts from both the approaches to combine or derive, alleviating the advantages of both methods. More precisely, the authors found that 10 contributions in which the results are approaches can be divided into three different groups representing the different integration strategies between the two fields. A group of contributions modified some concepts and tools in both two original fields in order to obtain a new original proposal, so it is called a "consolidated type" of contribution. Diversely, suitable TRIZ tools are extracted by the second group proposals for supporting specific phases of the HCI (combine-type). Another group proposal suggests imitating the TRIZ tools to generate similar HCI tools (suggest-type). In addition, most of the approaches correspond to the analysis and creation phase of the design. Only two approaches involve the three phases of design, and there are the innovation-oriented ID approach [39] and IDIM [65], while there are no approaches which focus on the evaluation phase of the design (Table 3). This seems to indicate that the research on the synergy of HCI and TRIZ is not deep enough.

Indeed, from a problem-solving perspective, every method has a different position in analyzing problems and has different solutions, and it must not deny their contribution to the field of the synergy between HCI and TRIZ.

However, in HCI, many challenges have been triggered by the rapid advancement of technology. Rapidly evolving systems for interaction require novel processes that allow for rapidly developed designs, evaluations, and interaction strategies to facilitate efficient and unique user interactions with computer systems [80]. This indicates that the continuous evolution of the HCI discipline is essential to adopt the "speed" challenge [80, 81]. It is important to convert the HCI design process into a more flexible process to allow for creative design explorations rapidly. This problem will be inevitable for every product developer in the future. For the research on product innovation related to HCI, we only focused on extracting one or two tools from HCI and TRIZ for combination, aiming to utilize the positive characteristics of these two methods. It will be rejected by evolving market regulations.

Table 8: Publications concerning the synergy between HCI and TRIZ (the database is only the database where the author retrieved this paper, the publisher, and the copyright are not considered).

Reference	HCI tools	TRIZ tools	Research method	Type of outcome	Domain	Database (journal, conference)
[76]	Usability	Contradiction	Case studies	Workflow	HCI	IEEE Xplore (C)
[61]	Laws of Interaction Design	Effects Database	Case studies	Method/ methodology	HCI	Elsevier Science Direct (J)
[39]	Interaction Paradigms	Ideal Final Result (IFR)	Case studies	Method/ methodology	HCI	Elsevier Science Direct (C)
[62]	Usability	Trends	Experimental design	Method/ methodology	Engineering	Engineering Village (C)
[60]	Interaction Pattern Libraries	Inventive Principles	Literature review	Opinion	HCI	Springer Link (C)
[63]	Interaction Pattern Libraries	Inventive Principles	Survey	Tool/toolkit	HCI	Scopus (C)
[11]	Usability	Contradiction	Case studies	Metric/ measurement	HCI	Web of Science (J)
[12]	Usability	Contradiction	Survey	Method/ methodology	HCI	Engineering Village (J)
[77]	Nielsen's Heuristics and Norman's Design Principles	Effects Database	Case studies	Practitioner guidelines	Health and safety	ACM Digital Library (C)
[64]	Usability	Inventive Principles	Experimental design	Model/framework	Computer science	Springer Link (C)
[65]	Usability	Inventive Principles	Experimental design	Model/framework	HCI	Springer Link (J)
[13]	Laws of Interaction Design	Contradiction	Literature review	Method/ methodology	Engineering	Elsevier Science Direct (J)
[22]	Usability	Effects Database	Literature review	Design recommendation	HCI	Springer Link (C)
[66]	Laws of Interaction Design	Contradiction	Case studies	Method/ methodology	HCI	Springer Link (C)
[78]	Laws of Interaction Design	Contradiction	Statistical analysis	System prototype	Engineering	IEEE Xplore (C)
[67]	Usability	Trends	Case studies	Model/framework	Engineering	Springer Link (C)
[79]	Usability	Inventive Principles	Literature review	Design recommendation	Engineering	Springer Link (C)

In such a context, the following three significant gaps were drawn in the conducted review. The future research on the integration of TRIZ and HCI may face the gaps:

(i) There is too much focus on the integration of one or two of both tools, but lack of HCI and TRIZ system integration.

(ii) The design process is too complicated, or the time and cost are too high, ignoring the expectations of industry practitioners for the HCI design approaches.

(iii) The performance of the proposals has not been comprehensively evaluated.

5.3. Recommendations for Future Work. As mentioned above, the possible reasons for the gaps are as follows: HCI is a multidisciplinary field, it contains a variety of methods and tools, TRIZ is a theory and an approach, and they have different purposes. HCI methods or tools are not as structured as the TRIZ, and very often it is very difficult to apply them in an effective way. And there is a lack of clarity regarding the nature of design processes involved in the HCI field and the role of design and design thinking in HCI research and practice. In addition, the extraction and combination of different tools from HCI and TRIZ caused the randomization of the evaluation criteria.

All of these seem to suggest the creation or definition of a standard in the field of HCI. It should include a clear list of all tools, open structure division of the involved areas, and industry-recognized evaluation standards. Indeed, this is a hugely time-consuming and labor-intensive challenge, but it is derived from market demand.

In addition, through the analysis of analogies and differences between HCI and TRIZ (Section 2.5), the authors found that there is no HCI tool similar to the "TRIZ Contradiction." However, there are indeed contradictions between the user input and computer output in HCI [12, 14]. Therefore, the HCI contradiction is one of the breakthrough points in the future work of the synergy between HCI and TRIZ, but it involves the quantification of user behaviour, which is also a challenge.

Table 3 shows that there are three approaches using the "TRIZ Contradiction," there are the IDGL framework [12], the integrating user information method [13], and the human-centered innovation process method [66], respectively.

These three approaches not only use the tools in HCI and TRIZ but also extract the auxiliary tools about user needs. Among them, the most used auxiliary tool is QFD. This result shows that the tools for the conversion of user needs are missing in the HCI and TRIZ systems. Therefore, the transformation of user needs is another direction for the future work of the synergy between HCI and TRIZ.

5.4. Study Limitations. The review is not without limitations. Although a rigorous system search conducted, it is possible that may have missed some pertinent studies, considering the wide area covered by HCI.

In addition, Filippi and Barattin have in-depth research on the synergy of ID and TRIZ. Of the 17 publications, 5 publications [11, 12, 39, 62, 65] are directly or indirectly related to them, which has a certain potential impact on the objectivity of the sample. Although the protocol and different analysis methods are used to objectively measure the samples and the results are not much different, it is still necessary to find a sample standard to make the research more objective.

Since the literature review is primarily focused, the set of recommendations was exclusively based on publications of the sample. Authors believe that recommendations for the synergy between HCI and TRIZ can greatly benefit from existing knowledge in other areas for example artificial intelligence and intend to address these limitations in future studies on the synergy between HCI and TRIZ.

6. Conclusions

This paper presents a literature review of contributions in the area of the combination of HCI and TRIZ for product innovation. Specifically, the current state of the literature is derived for enhancing HCI by using the potential synergy with TRIZ. To this end, all the related publications were analyzed in an unbiased way. Considering the content of the papers, the trends of synergy between HCI and TRIZ, design methods integrated by different tools and motivations, the most commonly used research methods and output results in this field have been detected.

Regarding the contributions, on the work conducted by the authors, the authors found that 10 contributions whose research results are approaches can be divided into three different groups representing the related integration strategies for the two fields. New original proposals are obtained from the two modified original methods through the merge-type contributions. Also, suitable TRIZ tools are extracted by the combine-type contributions to support specific phases of the HCI. The suggest-type group suggests imitating the TRIZ tools to generate similar HCI tools. The surveyed literature does not provide sufficient information for assessing and systematically comparing the methods. We analyzed these contributions with the design phase approach and found three lacks. In general, the method of synergy between HCI and TRIZ at this stage is not enough to be fully qualified for the innovative design of HCI products. For future work, authors plan to start with quantifying user behaviour and resolving interaction contradictions and then gradually establish the HCI standard system.

Moreover, many different research hints can be extracted from this work. More precisely, researchers aimed at exploiting the benefits of HCI and TRIZ will find here a comprehensive review of past attempts, with important considerations about industrial needs, methods, and functional concepts.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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