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Framework for Evaluating Solution Concepts in TRIZ-based Inventive Designs Using a Functional, Behavioral, and Structural Modeling Approach

This study proposes an evaluation framework to explore the solution concepts generated by inventive design approaches in the concept generation phase of the engineering design process. The concept generation phase significantly impacts producing inventive solutions, as a failure at this stage can lead to time-consuming redesign and expensive rework without any solution. The proposed framework is focused on solving two problems at this stage: first, how to represent a solution concept that is not an obvious product but rather a rough idea capable of guiding designers to produce inventive solutions. And second, how to analyze the solution concepts to evaluate and compare with others. The evaluation framework is based on the classical Gero's function, behavior, and structure product modeling formalism. The capability of the proposed evaluation framework is initially tested through its application to solution concepts generated by inventive design approaches like the Russian Theory of Inventive Problem Solving TRIZ.

Keywords: *evaluation, inventive design, decision-making, conceptual design, problem-solving, FBS evaluation framework.*

1. INTRODUCTION

The decision-making step is fundamental to inventive design solutions in the engineering design process. Generally, the engineering design process has three main stages: concept generation, embodiment, and detailed design [1]. The concept generation phase in the engineering design process is the most important, as failure at this stage can lead to time-consuming redesign and expensive rework without any solution. This leads to disadvantages of delay in launching products into the market. In past decades, academic researchers, as well as companies, have continually developed approaches that help them in the concept generation phase to produce inventive solutions to survive in competitive markets. These approaches are mainly classified into two categories, i.e., intuitive/traditional inventive design approaches and systematic inventive design approaches [2,3]. These inventive design approaches generate several Solution Concepts (SC) in the concept gene–ration phase. SC is not a real product or solution/ structure that can be presented in terms of physical rep–resentations like a CAD 3D model etc., but it is an idea for a solution that has the capability to guide project partners (designers, experts, research, and development (R&D) and top management of the company, etc.) to produce inventive solutions/product to the problem(s). It consists of several elements, i.e., functions, parameters, problems, contradictions, requirements, etc.

However, generating inventive solution(s) from SC is a big challenge because there is no method for evaluating and comparing inventive design SCs at the concept generation step of the design process. Due to these limitations, the project partners select conventional solutions instead of focusing on the SCs to produce inventive solutions. From this perspective, there is a research gap in methodological approaches; all the existing inventive design approaches need more rigo–rous methods for evaluating SCs in the concept gene–ration phase. To deal SCs in such situations, there are two main problems to answer: how to represent an SC that is not a product but an idea with several elements. The second problem is developing methods to evaluate and compare important elements of SCs in inventive design.

To address this situation, this paper makes two contributions: (i) a model of representation of SC to help designers to define and represent SCs, and (ii) a framework containing a set of steps for evaluating and comparing the SCs. The model is based on classical Gero's function, behavior, and structure (FBS) product modeling formalism [4], and it focuses on how designers for inventive design problem solutions can analyze the SCs to produce inventive solutions. These are all done by combining already existing methods and approaches. What is unique to this evaluation framework is that it is not just a use of existing methods. Still, we have combined some existing methods in such a way as to propose our own method of building a new evaluation framework that can allow us to compare two or more SCs and, as outcomes able, to produce an inventive solution(s).

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As a first step of evaluation framework validation, in this study, the proposed evaluation framework is applied to SCs generated in one of the systematic inventive design approaches like the Russian Theory of Inventive Problem Solving (TRIZ) [5] and its extension tools as Inventive Design Method (IDM). We also acknowledge that this research contribution is intended to be one of many focuses; our future work will also explore and incorporate other methodologies and approaches.

After this introduction, in section 2, a brief state-of-the-art relevant to our work is presented. Section 3 proposes an evaluation framework based on FBS product modeling formalism to explore the SCs. The approach of the evaluation framework is detailed with a pedagogic example of table design in section 4. Section 5 includes a discussion. Finally, section 6 presents the conclusion, contribution, and future perspective.

2. BACKGROUND AND PRIOR WORKS

Before going into details of the evaluation framework, this section presents some background studies for different inventive design approaches that exist for inventive solutions and their limitations in evaluating SCs. To solve problems, and develop inventive solu–tions, it is important to generate SCs by using inventive design approaches. Many so-called inventive design approaches available in scientific literature, online platforms, books, etc., can help produce inventive solutions. These approaches are different regarding the mechanisms they use to generate SCs. The exact number of these inventive design approaches is difficult to mention. Literature shows that more than 300 met–hods for inventive design approaches exist, as claimed by [6,7].

Initially, during this research, the literature review identified more than 50 inventive design approaches relevant to the initial steps of the engineering design process. However, many approaches were only useful in the initial steps of the problem-solving phase before the concept generation phase. e.g., Factorization [3] and plus, minus, interest (PMI) approaches, etc., are only useful for understanding the problem but not in the ideas-generating phase[8]. Also, some approaches were not clearly detailed about their implementation steps, and there was no surety of the usefulness of the approaches in the concept generation phase, like Prototyping[9].

Thus, in the end, this study managed to narrow down the number of inventive design approaches shown in Figure 1 which have attracted the attention of researchers and organizations in the last two decades and are useful for generating SCs in the concept generation phase. Also, this study identified and focused on the inventive design approaches on which modern tools have been applied, like TRIZ and its extensions such as IDM, inverse problem graph (IPG) [10], etc.

After analyzing the inventive design approaches, it was identified that the SCs resulting from these inventive design approaches are usually described in a declarative manner or presented as sketches or verbally, which cannot possess any further details. Ultimately the project partners feel it easy to go for conventional solutions by focusing less on these generated SC, as shown in Figure 2.

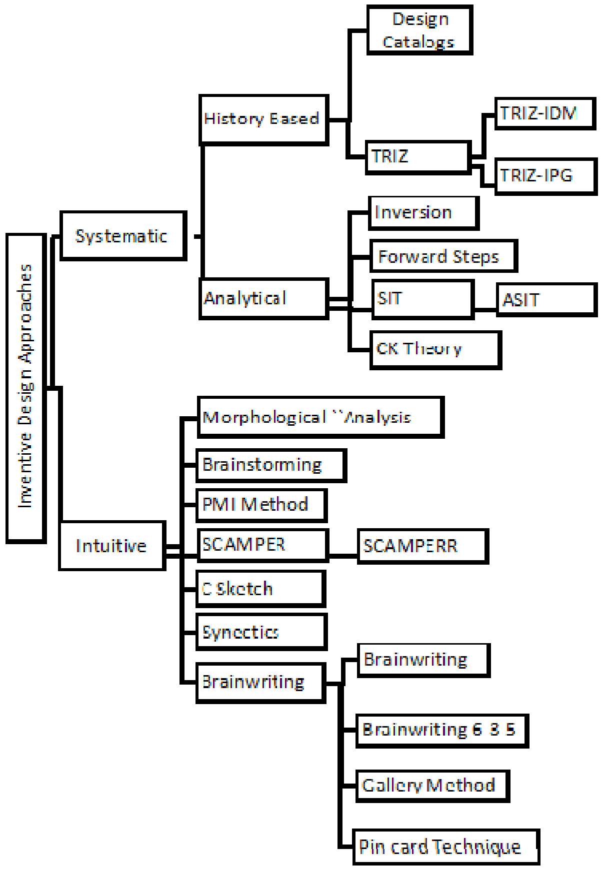


Figure 1. Classification of inventive design approaches

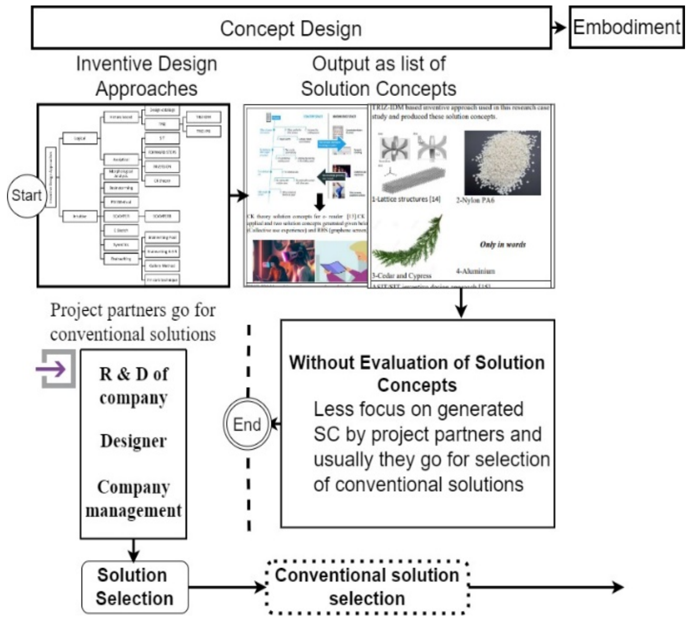
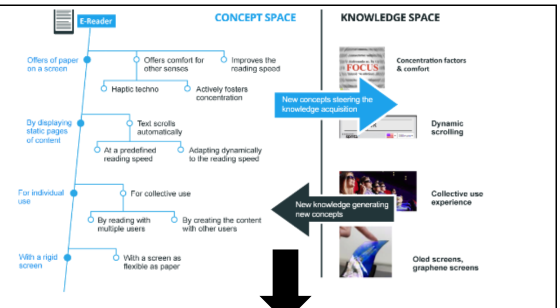
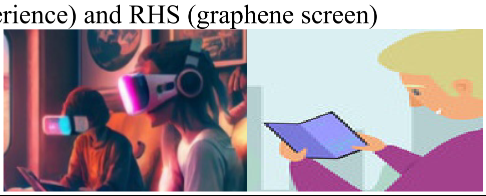
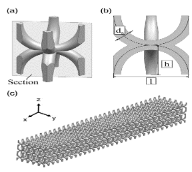


Figure 2. Absence of evaluation framework results in the selection of conventional solutions

Some examples of inventive design SCs are given in Tabele 1. This situation shows a research gap regarding methodological approaches that the existing inventive design approaches need more rigorous methods for evaluating SCs in the concept generation phase, and the results could be more successful if we apply rigorous evaluation at this phase.

Evaluation methods are referred to as methods that provide improved and more detailed knowledge for decision-making steps mostly used in the final design alternatives selection. It is also important to make it available in the initial step of concept design, where there is always a lack and/or loss of information.

Table 1. Examples of inventive design solution concepts

 **(1)** CK theory solution concepts for e-reader [11].CK Theory was applied, and two solution concepts were generated, given below LHS (Collective use experience) and RHS (graphene screen) 
(2) TRIZ-IDM-based inventive approach used in this research case study and produced these solution concepts.  Lattice structures [12]  Nylon PA6  Cedar and Cypress ***Only in words*** Aluminium
(3) ASIT/SIT inventive design approach[13]. A telecom company faced a documentation issue, and the SIT proposed two solution concepts. **1**-The document collection process with the welcome visit. **2**-The document verification executive should follow up with the franchisee for three days to complete the documentation and then collect it even if it is incomplete. However, upon little analysis, these solution concepts need more details (evaluation) to be useful for producing solutions.

3. PROPOSED EVALUATION FRAMEWORK FOR SOLUTION CONCEPT

Based on the discussions, the inventive design SCs has no structural design available for the final product. To deal SCs in such situations, there are two main contributions of this paper as given:

- The representation model of SC.
- Evaluation framework for analyses and comparison of SCs in inventive design approaches.

3.1 Solution Concept Representation

The inventive design SC is an idea that is not materialized in terms of a product but is capable of fulfilling the intended functions of the expected product. This indicates that a set of few fundamental design domains, such as FBS domains, may represent the main features of an SC. The literature review shows that there needs to be more focus on functional and behavioral aspects of SCs in inventive design approaches. But this study confidently suggests that an SC must fulfill certain functions and behaviors, and by fulfilling these functions and behaviors, the SC could lead to a solution or structural solution, and it is formally expressed as:

$$f(F,B) \to S \tag{1}$$

The generic schematic of how SC representation modeling concerns FBS domains shown in Figure 3 is already presented in [14].

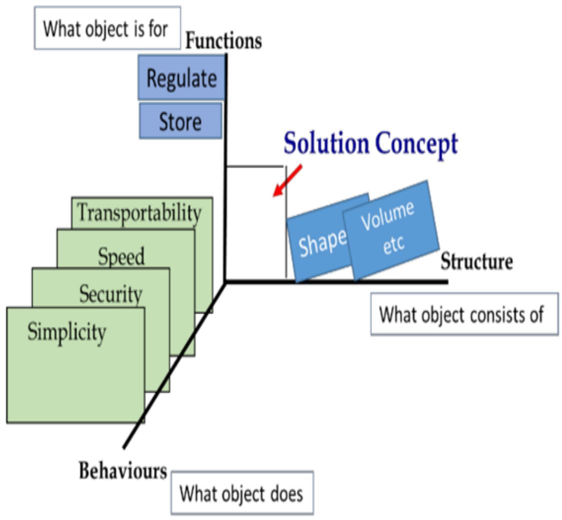


Figure 3. FBS aspects of solution concept representation

Before going into details of the evaluation framework, it is important to elaborate on the term FBS from the perspective of this research. Due to the importance of function, behavior, and structure in engineering design processes, there are countless definitions, descriptions, and discussions about them in the research community. The FBS initially defined by Gero [15–17] is part of this research. When dealing with FBS, there is often confusion between function and behavior [18]. According to Gero [19], the term function describes what it is for, behavior describes what it does, and structure defines what an artifact is. In the following below, each term is elaborated in the context of this study.

- **Function**

Functional requirements illustrate what an artifact should do for a possible solution. Gero defined function as “the design intentions or purposes” [20,21]. Some general examples of functions initially provided by [22] are separate, transfer, change, control, destroy, initiate, intensify, lower, modulate, raise, create, destroy, generate, accumulate, check, indicate, inspect, measure, setup, stabilize, etc.

The function of any system or artifact is very difficult to define objectively (without human opinion) because functions are requirements and intentions which are the product of the imagination of designers or customers. Take the example of a wooden table func–tion; a designer can imagine that one of its functions is "to support items" and another designer "to provide cover in case of earthquake”, even if the designers observe the same behavior “resist external loads”. Therefore, the function is related to both physical behavior and human perception of behavior, i.e., objectively and subjectively, respectively.

- **Behavior**

Gero defined behavior as “how the structure of an artifact achieves its functions” [20]. Behavior can be illustrated by the physical states of an artifact and the laws of physics, which shows that behavior can be defined objectively (with or without being influenced by personal opinions or feelings) as changes in physical states. For example, the behavior of a wooden table can be resistance to external load, reflection (color) and chemical and thermal reactions, etc., with respect to the functions of that table. Some common examples of behavior are chemical reactions, thermal reactions, impact load resistance, reflection, friction, maintainability, durability, etc., [23,24].

- **Structure**

Gero defined structure as “the components that make up an artifact and their relationships” [20]. In structure, geometry, dimensions, topology, material, shape, loca–tion, and other physical properties are defined in connection to produce a technical solution (structural artifact) that satisfies the required functional and behavioral aspects.

Table 2. Different domains of the design world

Different domains	Functions	Behavior	Form/Structure which fulfills required functions
Mfg. (Manufacturing)	Product functional requirement	How structure fulfills requi–red functions	Physical aspects/architectu ral aspects
Software	Output	How structure fulfills requi–red functions	Algorithms and input variables
Materials	Required properties	How structure fulfills requ–ired functions	Microstructure/ composition of material
Systems	Systems functional requirement	How structure fulfills required functions	Machines or components and subcomponents

The term FBS is used in many fields, such as production, manufacturing, services, software, etc., shown in Table 2.

3.2 Evaluation Framework

When dealing with inventive solutions, satisfying func–tional requirements is one of the primary requirements. Also, in this concept generation stage, the product's structure still needs to be defined, and the designer needs more data or information about the final product or structure so the expected structural domain is considered. Therefore, the proposed evaluation frame–work for SCs focuses on the final product's intended functional, expected behavioral, and expected structural domains. In this way, the result is the evaluated SCs in FBS aspects. The main objective of using FBS modeling is to deal with SC first by evaluating func–tion(s) through function(s) decomposition subjectively (human judgment), then focusing on the semantic aspect, such as the FB relationship, and further by using behavior as a bridge to link intended function and expected structure relationship. Below is the detail of the five steps evaluation framework followed by a case study application.

Step 1- Data collection
Step 2- Function Identification
Step 3- Function-Behavior FB relationship
Step 4- Function-Behavior-Structure FBS relationship
Step 5- Comparison of solution concepts

The proposed evaluation framework consists of five main steps, shown in Figure 4.

Step 1- Data collection

After SCs produced by the inventive design approaches, the SCs are the main inputs of this evaluation framework. In this step, the method initially helps to gather all the related information, data, technical drawings, and documents about the SC(s). This process includes a detailed discussion with designers, customer, and other experts involved in the initial problem formulation, etc., which increases the authentication of these data and avoid loss of information.

As there is no final product or solution available at this stage, the project partners try to identify the general main parts of the product and, if possible, present a general schematic of major parts or components to be present for the final solution. This general schematic will be a reference point for the final comparison of SCs and identification of s expected structural domain. Also, At the end of this step, the project partners identify a list of major issues related to each part and consider them as important requirements to be focused on for the main product/system under consideration.

Step 2- Function Identification

Following the information collected in the first step, the second step identifies the intended functions and main function(s) of the expected product relevant to the initial identified problem(s). Function like transfer, change, control, destroy, initiate, intensify, lower, modulate, etc., identify and then converts to symbolic functions, e.g., "to support objects", "to provide navigation," and "to stop movement," etc.

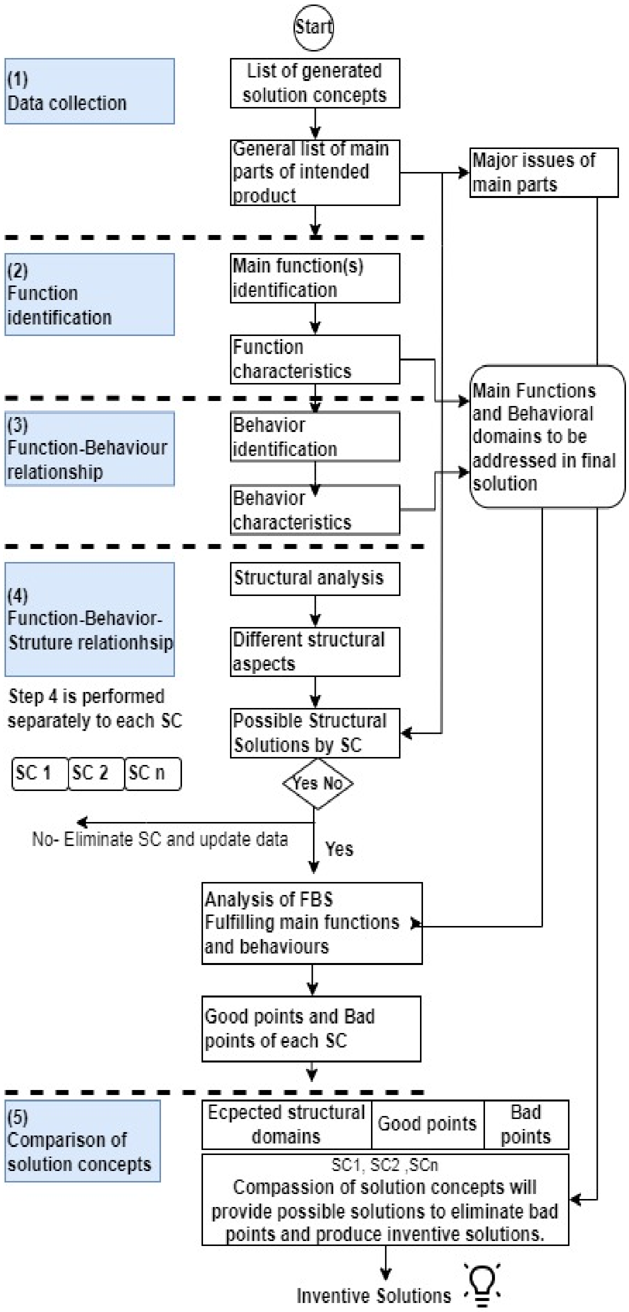


Figure 4. Proposed evaluation framework for solution concepts.

As discussed earlier, that function is generally qualitative in nature and symbolically denotes with (to + verb). It is hard to scale functions directly by using symbolic functions. So next thing needs to elaborate function in such a way that it gives more details of the function. So, to cope with this challenge, we have decomposed function into “function characteristics" by the input of project partners and then identified the most important characteristics by using a semantic differential (SD) scale, which makes way to link expected behavioral aspects with quantifiable data in the next step of function behavioral relationship.

Step 3- Function-Behavior FB relationship

In step 4, after the function decomposition, based on all the information gathered from previous steps, the project partners now identify a list of related expected behavior and behavior characteristics of the product under consideration. The identification of related expe–cted behavior (s) and behavior characteristics(s) is made by project partners using the same procedure of the SD scale.

At the end of this step, the project partners identify the main intended function(s), function characteristic(s), expected behavior(s), and behavior characteristic(s) of the main product to be designed.

Step 4- Function-Behavior-Structure FBS relationship

In this step of the structural relationship, the project partners identify the expected structural domain, as there is no structure or final solution available at this stage of the design process.

So, in this step, the product's expected structural domain(s) will be identified with an analysis of the generated SCs. In this step, each SC is analyzed separately by identifying its capability to give a solution in any aspect of the structure. The different aspects of the structure domain are shown in Table 2. If the structural domain is not possible, then the SC is not further considered. The SC, which can be used in any aspect of the structural domain, is further analyzed in terms of capabilities to fulfill the identified functional and behavioral characteristics from steps 2 and 3. This analysis result is identified as “good points “and “bad points” of SC and identified in the respective Colum of the final table.

This step is performed one by one to all available SCs, and the result is documented in the FBS analysis table, which is used in the final next step of comparison for producing possible solutions.

Step 5- Comparison of solution concepts

This last step of SCs comparison has three main inputs.

- The SCs can produce solutions to any aspect of the structural domain of the final product.
- The good and bad points of each SC were identified in the previous step.
- The general main parts of the final product and their major issues are to be addressed as identified in step 1.

After comparing all the SCs, the project partners will be confident enough to give inventive solutions to the initially mentioned problems regarding designing the final product or any system.

4. APPLICATION CASE

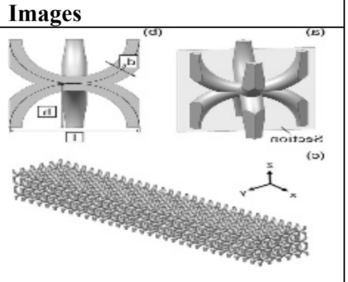
The chosen application case is a pedagogic example of designing a table with inventive solutions to problems. The initial problem, in this case, the initial problem is that the product "table" designed or produced with conventional methods is not lightweight when the user needs to move it, can be damaged easily, has less lifet–

ime weight, etc. To produce inventive problem solutions in such cases, in the engineering design process, several inventive design approaches have been proposed in the literature using various methods shown in Figure 1, including TRIZ-IDM [25].TRIZ-IDM is frequently used to generate SCs in the initial concept generation phase of the engineering design process. TRIZ-IDM is based on the contradiction matrix and inventive principles of TRIZ. The contradiction matrix and inventive principles are the most known and simplest tools of TRIZ [26].

Like other inventive design approaches, the TRIZ-IDM approach does not offer precise and immediately applicable solutions but rather ideas giving hints to produce solutions or simply called SCs[5],[27].

For the application case study of the table design problem, a list of several SCs generated by the TRIZ-IDM inventive design approach is shown in Table 3.

Table 3. Solution concepts generated by TRIZ-IDM inventive design approach.

Solution concepts	Images
(1) The ARCH **lattice** structures have superior energy absorption and mechanical properties.	
(2) **Cedar and Cypress** Long-lasting	
(3) Nylon PA6 produce strength, light weight, strength, stiffness, etc.	
(4) **Aluminum** is lightweight, less costly,	Only in words

After generating and providing a list of SCs in the concept generation phase, a scientific question arises about which SC should focus on before going to the development phase arises. The designer must use a model to evaluate the SCs and, based on these evaluated results, select the better SC or combination of SCs for producing solutions to problems. The generated SCs are analyzed using the proposed evaluation framework in the following steps.

4.1 Step 1- Data collection

They are starting with the first step of data collection. The related information regarding the SCs shown in Table 3 is collected from customers, designers, and the project's top management (project partners). The details of the inventive design approach TRIZ-IDM used for generating these SCs also studied to collect useful information. Details of how to formulate the initial problem analysis can be seen in [28]. After collecting all relevant data, providing a general schematic of the final solution's major parts is necessary. In the case of inventive design SCs, there is no final product structure available at this stage, so as a reference point, a general schematic of the main parts of the product "table" is illustrated with its major parts given below:

- Top
- Apron
- Stretcher
- Legs

Given the initial problem, and project partners' requirements, the final solution of the table to be designed must focus on the following main criteria, and both the results are combined in a table as shown in Table 4.

- Cost
- Weight
- Fabrication time
- Recyclability
- 3D fabrication
- Rigidity
- Durability

Table 4. Major issues related to the main parts of the table.

	Structure parts	Major Issues to Address
1	Top	Weight, ergonomics, recyclability, Cost
2	Apron	Stable, rigid, recyclability, Cost, weight
3	Stretcher	recyclability, Cost
4	Leg	Energy absorption, light weight, recyclability, Cost

Step 2- Function Identification

In this step, using the data collected in the first step, a list of the product's related intended function(s) is identified with the involvement of project partners. A list of related intended functions is identified for the intended product "table" solution, shown in Table 5.

Once intended functions are identified, these functions need to be analyzed. As discussed earlier, the function of any system or artefact is very hard to define only objectively (without human opinion) because functions are requirements and intentions which are the imagination of designers or customers based on Gero's definition of the function. In this study, one of the known dimensionality reduction techniques, Semantic Differential scales (SD scale) [29], is suggested to use as a quantifying chart. Why this study recommends this because this rating scale is a highly rated quantifying method that allows individuals and organizations to measure stakeholder's views or attitude lies to a statement on a bipolar adjective scale (i.e., with opposite meanings), each representing a seven-point scale or five-point scale for function or function related characteristics, so that function is quantifiable. In this case, the main function identified unanimously is "to assist walk".

Table 5. List of related functions for SCs

Intended Functions	Main function(s)
• To Provide partition • To provide the heat (in case of burns) • To provide shelter (pets, etc., in case of rain) • To provide shelter (in case of an earthquake • To stop door movements • To support objects	• **To Support objects**

The main function, which was identified symbo–lically as "*to support objects,"* then further decomposed in this step with their intended characteristic(s) and to further subcategories of characteristics with the input of project partners. The list of first category-related characteristics is identified and shown in Table 6. The most important characteristic(s) are identified using SD Scale subjectively by inputs of project partners.

The SD scale chart can be used in any step where there feels necessary to quantify the qualitative data. To understand how SD scale works, an example of how to use the SD scale to quantify function characteristics for the artefact "table" under consideration is shown in Table 6. To understand and prepare an SD scale, you must first think of a number of words (functions, behaviors, characteristics, etc.) with opposite meanings that are applicable to describe the main function of the intended final product, as shown in right and left co–lumn of function characteristic in Table 6. The quan–tifying chart SD scale consists of three main columns with weightage in the center, and function charac–teristic(s), opposite of it, is given on the left and right sides, respectively. The final selection is the highest weighted characteristic(s). Using such quantifying chart gives more detailed and confident information on qualitative data involving human intentions.

Table 6. Characteristic(s) quantifying chart

Name /No:	Solution (Table)					
Function	To (support) objects					
Function characteristic	1	2	3	4	5	Function characteristic
1-Flammable	*	o				**1**-Flam resistant
2-High price			+ o	*		**2**-Low price
3-Unpackable		+	*o			**3**-Packability
4-less strongly			+	o	*	**4**-Strongly
5-Maximum weight			O +	*		**5**- Minimum weight
6-Limited Task			+	*		**6**-Multitasking
7- Less durable	+	*	o			**7**- Durable
8- Less shock absorption			+	O	*	**8**-shock absorption
9-Nonadjustable height			*	O +		**9**-Adjustable height
10-Single color						**10**- Multicolor
11- Noisy						**11**- Soft, quiet

Additionally, one thing to mention about project partners is multiple types of people. These different groups of people have different levels of knowledge but are in the same field. Despite the difference in the knowledge level, the final selection should be of that function or function characteristic(s), etc., which is top-rated. For example, in Figure 5, the selection of the most weighted characteristic no 2, 4, 7, etc., has been done by comparing the result of these three groups of people. It can be noted that there is variation regarding the scaling weightage, but the trend of the graph shows that the selected characteristic shown in Figure 6 is of high importance for all groups shown in Figure 5. The same comparison of different groups of people can be repeated for any step where it feels necessary for functions, function characteristics, behaviors, behavior, etc. This approach enabled us to comprehend how these factors collectively contribute to the overall function(s). In this way more confident result is achieved with less loss of information and more clarity. The final identified list of function characteristics is shown in Figure 6.

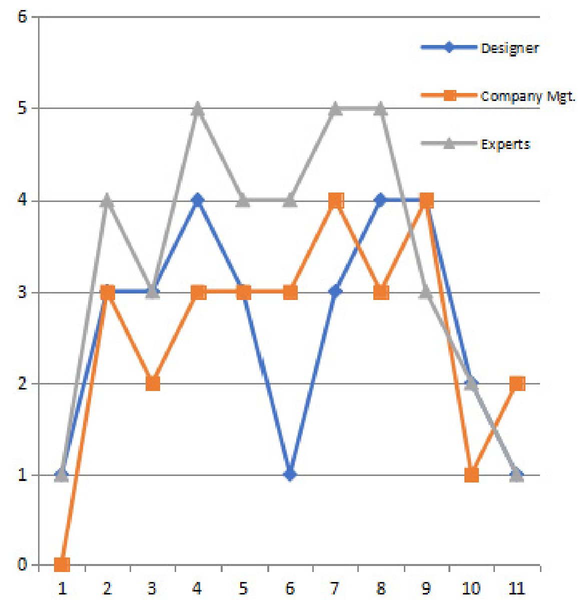


Figure 5. High importance characteristic from data acquired through quantifying table.

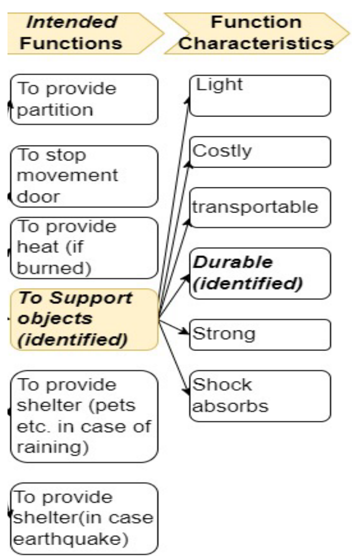


Figure 6. Main function characteristics identification

This function decomposition into function charac–teristics and then using the SD scale to narrow down the function's most important characteristic(s) is very important to link the function to expected behavior in the next step.

4.3 Step 3- FB relationship

In step 3, after the function identification, based on all the information gathered from previous steps, the project partners now identify a list of related expected behaviors of the product. The main function "to support objects" and the additional information on the function characteristics from Figure 6 helps to identify related expected behaviors, as shown in Figure 7. Using the same SD scale procedures, the most important expected behaviors list is identified from the list of expected related behaviors. The result is updated and highlighted, as shown in Figure 7.

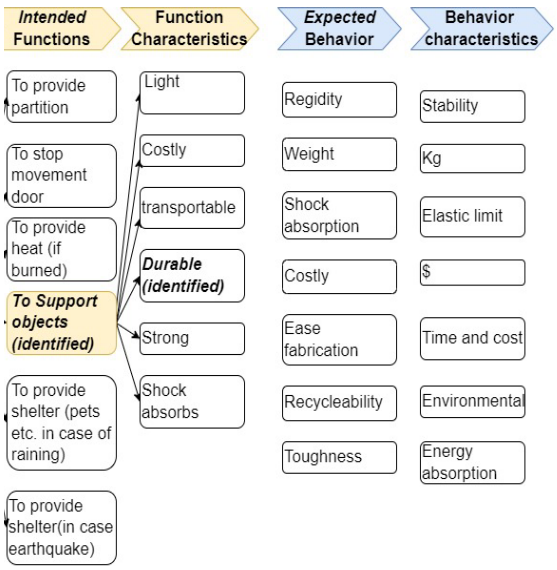


Figure 7. Function Behavior identification of an intended product

Moreover, before going to the next step of the expected structural domain, using the expected func–tion-behavior relationship with function characteristics, a list of related behavior characteristic(s) is also identified, as shown in Figure 7, which makes the beha–vior a bridge to link function with expected structure domain.

4.4 Step 4- FBS relationship

After identifying the product's main intended functions and expected behaviors, each SC from the list of SCs is analyzed with the identified functions and behaviors. The general major parts of the intended product and their major issues will be analyzed to see if the SC has the capability to use any structural aspect of the intended product with a focus on the major parts and their issues. In this step, only one SC, i.e., Lattice structure, is presented in Figure 8 to understand the FBS relationship of the process.

Equation (1) shows that SC is a subset of func–tion(s) and behavior(s), and by fulfilling these functions and behavior, the SC could lead to a solution/structure. So, in this way, SC's possible expected structural do–main can be identified by using the intended function-behavior of the intended product a.

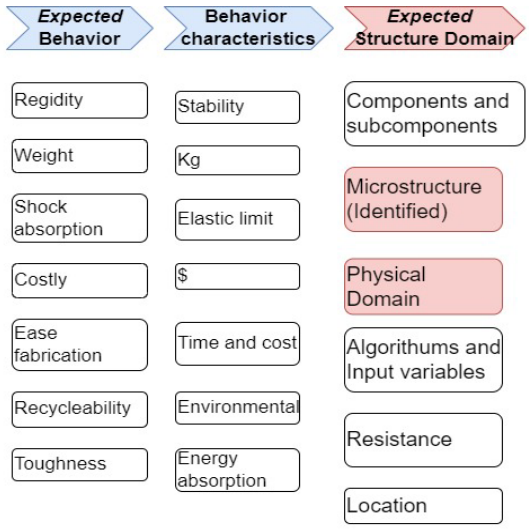


Figure 8. Function behavior structure FBS relationship of SC- lattice structure for the intended product

Step 5- Comparison of solution concepts

In the current SC of Lattice structure, the expected structural domain is related to the physical characteristic identified by project partners as shown in Figure 9, i.e., this SC could be helpful or have capabilities to give solution in the architecture domain of the final product, which means that there is a relation of this SC with the physical characteristic “architecture of product table” and this physical characteristic is very near to expected structural domain for the problem under consideration and the project partners will definitely keep this in mind and pay more attention during the generation of inventive solution(s).

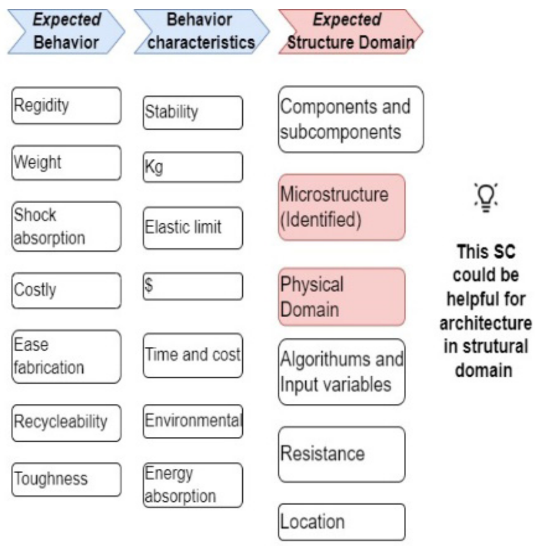


Figure 9. Possible structural domain identification by FBS analysis

Similarly, all the remaining SCs are evaluated in the same way, and results are stored. The final evaluation result is extracted and presented to stakeholders or pro–ject partners further to generate inventive solutions in accordance with the current situation and requirements.

The final extracted results of these SCs in the form of a table after evaluation of all is shown in Table 7.

The results obtained by SC evaluation based on FBS modeling provides confidence and help designers or project partners to produce an inventive solution(s) for the next steps of embodiment design.

Table 7. Final comparison table of SCs evaluation results

FBS result > *SCs*	**Expected structure domain**	**Remarks**
Lattice Structure	Shape, architecture Structural support	In architecture
Nylon PA6	Material composition	Possible in the composition of material for fabrication or suggestion for composite materials
Al	Shape, physical structure	Not suitable
Cedar and Cypress	Material composition	No suitable

5. DISCUSSION

Unlike the SCs generated in inventive design approaches, the proposed evaluation framework provides evaluated SCs focusing on the intended functional, expected behavioral, and expected structural domains, which gives more reliable data and insight into SCs capabilities and gives confidence to project partners to use these SCs to produce inventive solutions instead of going for conventional solutions. The final FBS evaluated result of SCs gives ways and confidence to project partners to produce inventive solutions to the problem under consideration. The SCs were initially given less attention due to a lack of evaluation but based on the evaluated results of SCs, the project partners were able to produce some inventive solutions. An overview of the schematic of how evaluated SC(s) by integrating an evaluation framework helps generate inventive solutions compared to non-evaluated SC(s) is shown in Figure 10.

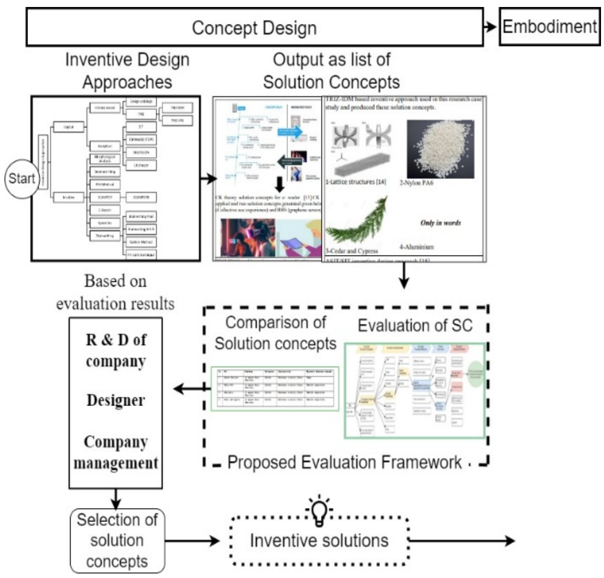


Figure 10. Evaluation of SC increases chances of inventive solution(s)

The selection of a solution is not part of the evaluation framework in this research, and it is upon the project partners to select a final solution and go for development. To give some additional info on the next steps, Figure 11 shows some parts of the solutions produced using the evaluated results of SC(s) by the project partners. The solution(s) could be extracted by combining all the SC(s), multiples, or only one.

Table 8 shows the position of the evaluation framework during the SC analysis for the table design highlighting its importance for the acceptability of SCs to solve problems.

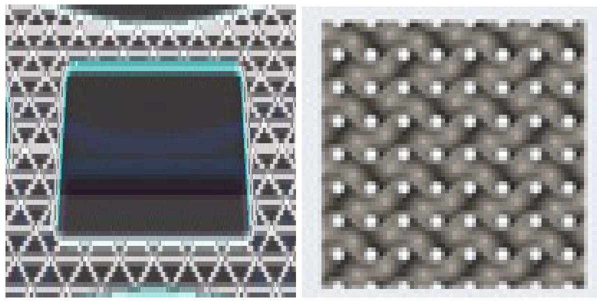
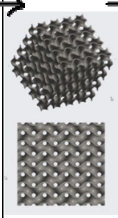
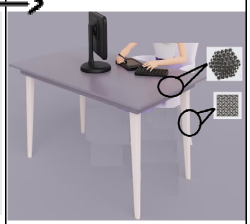


Figure 11. Close view of some parts of the solution produced using evaluation of SCs.

Table 8. Graphical abstract of evaluation framework position during inventive solutions

Solution concepts	**Evaluation of SCs**	Evaluation-based inventive solutions	Product concept
Initial problem statement and list of SCs 			

Based on the design results and some initial simulations of the table design, we have observed some good results, as given below:

- More Weight savings: 55.99 %
- Cost-effective.
- Increased rigidity
- Easily recyclable

6. CONCLUSION

Considering the improvement of inventive design approaches and the importance of evaluated SCs for inventive design outcomes, this study proposed using the FBS approach in the initial concept generation stage for inventive design approaches. Evaluation methods are the most essential inputs to inventive design app–roaches. Although evaluation methods are useful in the solution selection steps, it is also necessary to make them available in the initial step of concept designs, where there is always a lack and loss of information.

The evaluation framework for modeling and analysis of SCs presented here is a generic approach that attempts to ensure product functional and behavioral performance evaluation during the concept generation step of the design process. The framework presented allows the evaluation of the product's intended func–tional, behavioral, and structural domains. The evaluation method provides the designer with an indi–cator that informs how an SC can solve a product by focusing on FBS domains. The feasibility of our eva–luation framework is illustrated by a pedagogic example of SCs generated for a table design. As compared to the initial unevaluated list of SC(s), this evaluated result increased the attention of partners of the project to focus on these SCs. It produced some inventive solutions, indicating the feasibility of our proposed framework and encouraging its application to other inventive design approaches in future research.

By proposing the framework, this study makes two main contributions to the model of representation of SC to help designers to define and represent SCs, and a framework containing a set of steps for evaluating and comparing the SCs to produce inventive solutions.

The future challenge is how to integrate this method with other inventive design approaches, and we are working on this to extend the evaluation domains beyond FBS in future research.

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ОКВИР ЗА ПРОЦЕНУ КОНЦЕПАТА РЕШЕЊА У ИНВЕНТИВНИМ ДИЗАЈНИМА ЗАСНОВА–НИМ НА ТРИЗ-У КОРИШЋЕЊЕМ ПРИСТУПА ФУНКЦИОНАЛНОГ, БИХЕВИОРАЛНОГ И СТРУКТУРАЛНОГ МОДЕЛИРАЊА

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Ова студија предлаже оквир евалуације за истраживање концепата решења генерисаних инвентивним приступима дизајну у фази генерисања концепта процеса инжењерског пројектовања. Фаза генерисања концепта значајно утиче на производњу инвентивних решења, јер неуспех у овој фази може довести до дуготрајног редизајна и скупе прераде без икаквог решења. Предложени оквир је фокусиран на решавање два проблема у овој фази: прво, како представити концепт решења који није очигледан производ, већ груба идеја која може да води дизајнере да произведу инвентивна решења. И друго, како анализирати концепте решења да бисте их проценили и упоредили са другима. Оквир евалуације је заснован на класичном Героовом формализму моделирања производа, понашања и структуре. Способност предложеног оквира за евалуацију се иницијално тестира кроз његову примену на концепте решења генерисаних инвентивним приступима дизајну као што је руска теорија инвентивног решавања проблема ТРИЗ.