

Accelerating Innovation in Civil Engineering and Building Design with the Development of Archi-TRIZ and QFD

by

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Accélération de l'innovation dans la conception des bâtiments par le développement de l'Archi-TRIZ et QFD

Hamidreza Hassanijajini

RÉSUMÉ

Premièrement, il existe une demande pour l'introduction de nouvelles méthodologies spécialisées favorisant l'innovation dans le domaine du génie civil. À la suite d'une revue de la littérature, il a été constaté que TRIZ est une méthodologie systématique en conception innovante, mais que son application directe dans le processus de conception des bâtiments est difficile. Ainsi, il a été pertinent de produire une matrice de contradictions personnalisée, appelée plus tard Archi-TRIZ, afin d'accélérer l'innovation dans le processus de conception des bâtiments.

Deuxièmement, cette thèse décrit l'élaboration de la matrice de contradictions Archi-TRIZ afin d'accélérer l'innovation dans la conception des composants non structurels des bâtiments. D'ailleurs, son utilité a été expérimentée pour la conception d'un projet de mur mobile. De plus, Archi-TRIZ pourrait également s'avérer bénéfique dans d'autres domaines du génie civil. Par la suite, l'idée de créer un site web ou une application mobile intégrant Archi-TRIZ pour en faciliter l'usage par les concepteurs a été présentée et discutée, et cette idée a été illustrée à l'aide de figures, tableaux et descriptions.

Troisièmement, pour accélérer l'innovation dans la conception des bâtiments, la méthodologie de la thèse a été enrichie grâce à l'ajout de concepts d'articles pertinents, de conceptions innovantes et d'approches créatives pouvant être utiles dans divers projets de génie civil et de conception architecturale. Des descriptions ont été ajoutées, et le contenu a été relié de manière logique à chacun des 40 principes inventifs de la méthodologie Archi-TRIZ, aboutissant ainsi à la création de plusieurs tableaux de synthèse. Par la suite, des exemples tirés de ces tableaux — chacun étant lié à un principe inventif spécifique — ont été proposés pour être intégrés dans un site web ou une application mobile pour les rendre plus accessibles, comme mentionné précédemment, dans le but d'accélérer l'innovation dans la conception des bâtiments en facilitant le processus de réflexion des concepteurs et ingénieurs civils.

Quatrièmement, afin d'aider les concepteurs à choisir les meilleures options issues d'Archi-TRIZ, la méthode de prise de décision QFD a été présentée et utilisée, tout en ajoutant davantage de fonctionnalités au produit en prenant mieux en compte les besoins des clients. Pour ce faire, les besoins des clients ont été considérés via la méthode qui a été appliquée après l'utilisation d'Archi-TRIZ. Avec l'exemple du mur mobile, le processus visait d'abord à choisir la meilleure option entre deux alternatives, puis à ajouter des fonctionnalités supplémentaires selon les attentes des clients. Chaque choix concernant chaque caractéristique du mur mobile a été classé et sélectionné en fonction des besoins des utilisateurs. En résumé, la méthodologie a été appliquée à deux reprises dans l'exemple du mur mobile afin de d'expérimenter l'utilité de la méthode proposée dans cette thèse.

VIII

Enfin, pour les travaux futurs, il est recommandé de créer différentes matrices de contradictions spécialisées pour différents domaines du génie civil, qui pourraient être appelées Hydro-TRIZ, Road-TRIZ, Structure-TRIZ, Renewable-Energy-TRIZ, etc. Il est également suggéré d'ajouter des exemples innovants spécifiques à chaque domaine, et d'inclure l'ensemble de ces éléments comme fonctionnalités supplémentaires dans l'application mobile ou le site web présentés dans cette thèse, dans le but d'accélérer l'innovation dans les différents secteurs du génie civil.

Mots-clés : TRIZ, Matrice personnalisée, Archi-TRIZ, Conception de bâtiments, Innovation, Architecture, 40 principes inventifs, Génie civil, Déploiement de la fonction qualité, QFD, besoin du client, Construction, Murs mobiles.

Accelerating innovation in building design with the development of Archi-TRIZ and QFD

Hamidreza HASSANIJAJINI

ABSTRACT

Firstly, there is a demand for the introduction of new specialized methodologies to foster innovation in the field of civil engineering. Following a literature review, it was found that TRIZ is a systematic methodology for innovative design, but its direct application in the building design process is challenging. Therefore, it was deemed relevant to produce a customized contradiction matrix, later called Archi-TRIZ, to accelerate innovation in the building design process.

Secondly, this thesis describes the development of the Archi-TRIZ contradiction matrix in order to accelerate innovation in the design of non-structural components of buildings. Its utility was then experimented in the design of a movable wall project. Moreover, Archi-TRIZ could also prove beneficial in other areas of civil engineering. Subsequently, the idea of creating a website or mobile application integrating Archi-TRIZ to facilitate its use by designers was presented and discussed, and this idea was illustrated using figures, tables, and descriptions.

Thirdly, to accelerate innovation in building design, the thesis methodology was enhanced by incorporating relevant article concepts, innovative designs, and creative approaches that could be useful in various civil engineering and architectural design projects. Descriptions were added, and the content was logically connected to each of the 40 inventive principles of the Archi-TRIZ methodology, leading to the creation of several synthesis tables. Then, examples from these tables — each linked to a specific inventive principle — were proposed to be integrated into a website or mobile application to make them more accessible, as mentioned earlier, with the aim of accelerating innovation in building design by facilitating the brainstorming process for designers and civil engineers.

Fourthly, in order to help designers, choose the best options derived from Archi-TRIZ, the QFD decision-making method was introduced and used, while also adding more features to the product by better taking customer needs into account. To do this, customer needs were considered through the QFD method, which was applied after the use of Archi-TRIZ. Using the movable wall example, the process first aimed to select the better option between two alternatives, then to add additional features based on customer expectations. Each choice regarding each feature of the movable wall was ranked and selected based on user needs. In summary, the methodology was applied twice in the movable wall example to experiment the usefulness of the method proposed in this thesis.

Finally, for future work, it is recommended to create different specialized contradiction matrices for various fields of civil engineering, which could be called Hydro-TRIZ, Road-TRIZ, Structure-TRIZ, Renewable-Energy-TRIZ, etc. It is also suggested to add specific

innovative examples for each field and include all these elements as additional features in the mobile application or website introduced in this thesis, with the aim of accelerating innovation across the different sectors of civil engineering.

Keywords: TRIZ, Customized matrix, Archi-TRIZ, Design building, Innovation, Architecture, 40 Inventive Principles, Civil Engineering, Quality Function Deployment, QFD, customer's need, Construction, Moveable Walls.

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LIST OF ABBREVIATIONS

AD	Axiomatic Design
ARIZ	Algorithm of Inventive Problem Solving
CDP	Coupled Design Process
CK Theory	Concept & Knowledge Theory
Ecatriz	Ecology-friendly approach TRIZ
GDT	General Design Theory
ID	Infused Design
IJDST	International Journal of Design Sciences & Technology
IJIDeM	International Journal on Interactive Design and Manufacturing
IP-1	Inventive Principle 1, Segmentation
IP-2	Inventive Principle 2, extraction
IP-3	Inventive Principle 3, Local quality
IP-4	Inventive Principle 4, Asymmetry
IP-5	Inventive Principle 5, Merging
IP-6	Inventive Principle 6, Universality
IP-7	Inventive Principle 7, Nested doll
IP-8	Inventive Principle 8, Anti-weight
IP-9	Inventive Principle 9, Prior counteraction
IP-10	Inventive Principle 10, Preliminary action
IP-11	Inventive Principle 11, Beforehand cushioning
IP-12	Inventive Principle 12, Equipotentiality
IP-13	Inventive Principle 13, The other way round

- IP-14 Inventive Principle 14, Spheroidality-curvature
- IP-15 Inventive Principle 15, Dynamics
- IP-16 Inventive Principle 16, Partial or excessive actions
- IP-17 Inventive Principle 17, Another dimension, moving to a new dimension
- IP-18 Inventive Principle 18, Mechanical vibration
- IP-19 Inventive Principle 19, periodic action
- IP-20 Inventive Principle 20, Continuity of useful action
- IP-21 Inventive Principle 21, Skipping
- IP-22 Inventive Principle 22, convert harm into benefit
- IP-23 Inventive Principle 23, Feedback
- IP-24 Inventive Principle 24, Intermediary
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- IP-36 Inventive Principle 36, Phase transition

IP-37	Inventive Principle 37, Thermal expansion
IP-38	Inventive Principle 38, Strong oxidants
IP-39	Inventive Principle 39, Inert atmosphere
IP-40	Inventive Principle 40, Composite materials
IPN	Inventive Principle Number
IPN 1	Inventive Principle Number 1
IQS	Innovation Situation Questionnaire
MIP	Inventive Principles
PFP	Problem Formulation Process
PLM	Product Lifecycle Management
QFD	Quality function Deployment
R&D	Research and Development
SMEs	Small and Medium-sized Enterprises
TRIZ	Russian acronym for Teorija Reshenija Izobretatelskikh Zadatch, meaning "Theory of Inventive Problem Solving"
4D	Fourth Dimension

INTRODUCTION

Innovation is a dynamic and multi aspect process that is inherently complex and influenced by various technological and economical factors. Successful innovation requires a balance between technical advancements and market demands. While market needs drive demand for new solutions, advancements in science and engineering enable the development of novel products. However, both technical feasibility and market acceptance must be carefully managed. Effective innovation strategies require to optimize cost, performance, and timing while considering consumer preferences (Kline & Rosenberg, 2010).

There are lots of innovation methodologies, like Trial & Error, the Algorithm of Inventive Problem Solving (ARIZ), TRIZ (a Russian acronym for "Theory of Inventive Problem Solving") (Cascini, 2012; Khomenko, De Guio, Lelait, & Kaikov, 2007), and Concept & Knowledge Theory (CK Theory) for innovation. The question is, why TRIZ has been chosen over these methodologies? The answer is that Genrich Saulovich Altshuller worked of ARIZ and through the evolution of this methodology and considering more than 40,000 patents to create TRIZ, he understood that most inventions have similarities. So, he invented the TRIZ contradiction matrix with 40 inventive principles, which is useful for accelerating innovation in many fields. TRIZ has been chosen between these methodologies because of its evolutions during decades and its consideration of numerous patents (Cascini, 2012; Khomenko et al., 2007).

TRIZ has been used in many fields, but its direct application in the building design process is difficult. Some researchers before this thesis, like Ahmed Cherifi et al., introduced Ecatriz, which is not for building design (Cherifi, M'Bassègue, Gardoni, Houssin, & Renaud, 2019; Hassaniyajini & Gardoni, 2022). So, we decided to introduce a specific contradiction matrix derived from TRIZ for designing buildings, called Archi-TRIZ, and examined it with a movable wall example (Hassaniyajini, Hassanimohebi, & Gardoni, 2024). Then, we designed a mobile application or website that includes Archi-TRIZ and gathered a few examples for each inventive principle in construction, civil engineering, structural engineering, and building design. By connecting each inventive principle with existing examples, we tried to help designers get inspiration to generate new innovative examples based on Archi-TRIZ's

recommended inventive principles for solving each contradiction, as well as previous innovative solutions. Then, in the next phase, we used Quality function Deployment (QFD) to consider customer needs in the innovative example. Finally, we applied this methodology in the second cycle to increase customer satisfaction (Cherifi et al., 2019).

This research introduce methodology to accelerate innovation in the construction industry by considering customer requirement factors, aiming to provide a comprehensive framework for its effective to accelerate innovation in the building design industry.

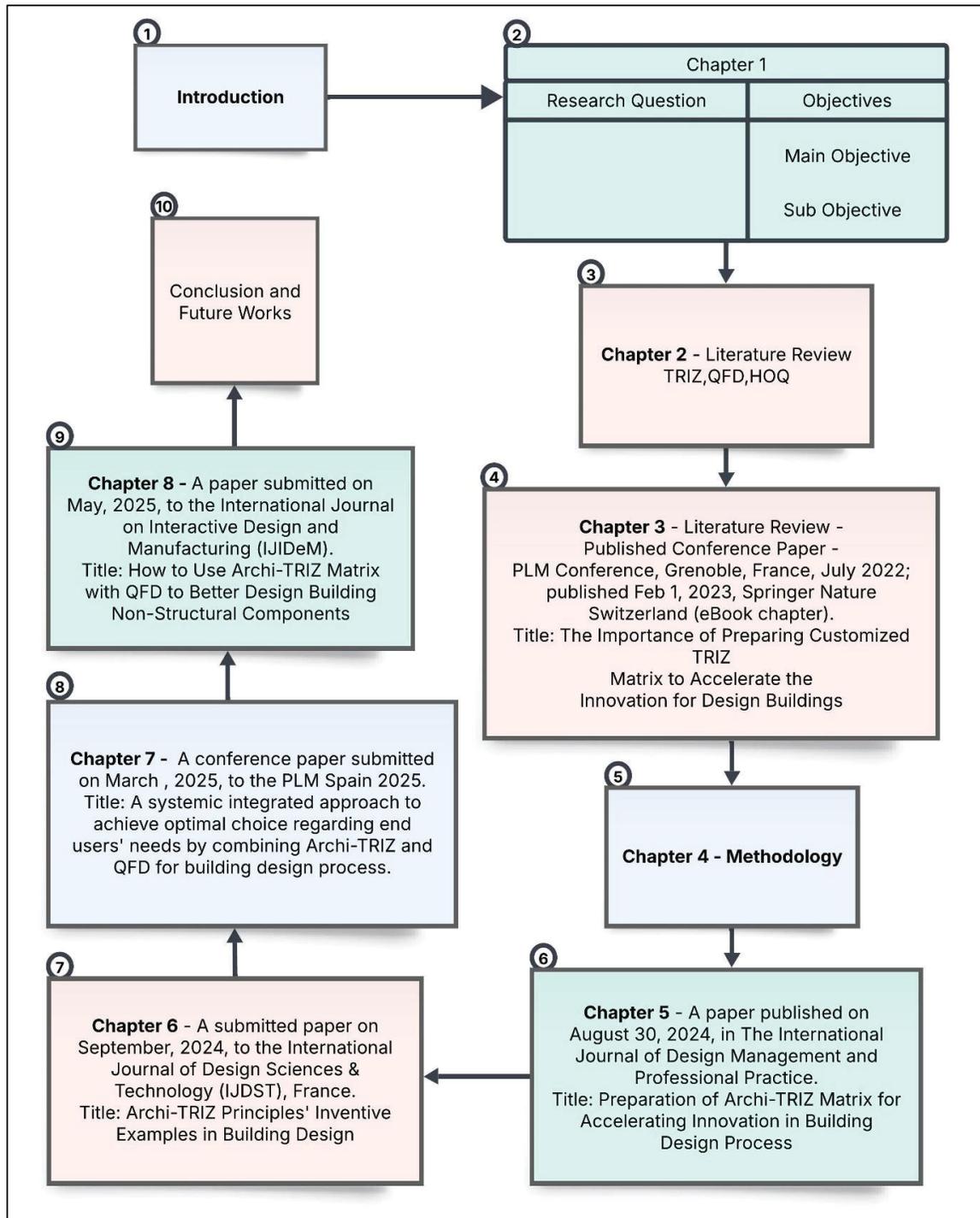


Figure 0.1 Thesis chapters

Figure 0.1 illustrates this thesis's chapters.

1. Introduction. In this part, there is an initial phrase explaining why innovation is important and what has been done in the papers in a nutshell.
2. Chapter 1 includes the research question, research objectives, and sub-objectives.
3. Chapter 2 includes the literature review of the thesis.
4. Chapter 3 includes the published literature review paper titled, “The Importance of Preparing Customized TRIZ Matrix to Accelerate the Innovation for Design Buildings” which was presented at the Product Lifecycle Management (PLM) Conference in Grenoble, France, from July 10–13, 2022. It was subsequently published on February 1, 2023, by Springer Nature Switzerland as a chapter in an eBook (Hassanijajini & Gardoni, 2022).
5. Chapter 4 covers the methodology of the thesis.
6. Chapter 5 presents a paper published on August 30, 2024, in The International Journal of Design Management and Professional Practice, titled “Preparation of Archi-TRIZ Matrix for Accelerating Innovation in Building Design Process” (Hassanijajini et al., 2024).
7. Chapter 6 features a submitted paper on September 9, 2024, to the International Journal of Design Sciences & Technology (IJ DST), France, titled “Archi-TRIZ Principles' Inventive Examples in Building Design”.
8. Chapter 7 includes a conference paper submitted on March 2025, to the PLM, Spain, titled “A Systemic Integrated Approach to Achieve Optimal Choice Regarding End Users' Needs by Combining Archi-TRIZ and QFD for Building Design Process”.
9. Chapter 8 is a paper submitted on May 2025, to the International Journal on Interactive Design and Manufacturing (IJIDeM), titled “How to Use Archi-TRIZ Matrix with QFD to Better Design Building Non-Structural Components”.
10. The last part is the conclusion and future work, which presents the conclusions of the thesis and highlights research gaps for future studies.

In a nutshell, this thesis includes two conference papers and three journal papers, introducing Archi-TRIZ to accelerate innovation while considering customer requirements through QFD.

CHAPTER 1

RESEARCH QUESTION AND RESEARCH OBJECTIVES

1.1 Research Questions

This thesis has several research questions that will be declared in the following.

- ❖ **RQ Paper 1:** In the first paper, the research question was: why is innovation so limited in the building design and construction industry?
 - ✓ The answer is because of lack of specific methodology in design building process.
- Is there any methodology that could be used to accelerate innovation in building design?
 - ✓ The answer is: yes, TRIZ is one of the innovation methodologies that could be used in the design process in many fields but its direct application in construction is difficult.
- What is the solution to accelerate innovation in building design?
 - ✓ The answer is: it is better to design a specific contradiction matrix for building design. lately called Archi-TRIZ in the second paper.
- ❖ **RQ Paper 2:** In the second article, the research question was: how could prepare a specific matrix by TRIZ?
 - The research objective was the preparation of Archi-TRIZ.
 - ✓ The result was: preparing website or mobile application that is showing innovative principles that could solve each contradiction of Archi-TRIZ.
- ❖ **RQ Paper 3:** In the third article, the research question was: how could we maximize and make it easy to use the Archi-TRIZ matrix for civil engineers and building designers?
 - The research objective was to gather innovative examples in different fields of civil engineering and add them to each inventive principle for brain storming to accelerate innovation not only in civil engineering projects but also in building design process.

- ✓ The result was: preparing several examples for each of the 40 inventive principles, arranged in multiple tables covering different civil engineering fields and project types. These examples will later be added to the website or mobile application mentioned in Research Question 2. Such inventive examples from different areas of civil engineering can assist engineers in brainstorming when designing various types of projects.
- ❖ **RQ Paper 4:** In the fourth article, the research question was: how could we consider customer's needs in design building process?
 - ✓ The answer is: It is possible to use QFD matrix for decision-making to choose the best option between the 2 options that come out of Archi-TRIZ. and also, to add more details to the prepared example by considering the customer's needs.
 - ✓ the result was: QFD matrix that has been used firstly to choose better option for movable wall example between two options that come out of Archi-TRIZ matrix.
- For examining this methodology: secondly, the details of the movable wall example have been designed and has been chosen by its ranking and scores. And these details have been added to the existed movable wall example.
- ❖ **RQ Paper 5:** In paper 5 the question was that: how could we add more details to the movable wall example?
 - ✓ The answer was: by repeating this methodology by using Archi-TRIZ and QFD for the second time. It is possible to design more details and choose based on customer's needs to maximize considering customer's needs.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Innovation is very important, but the lack of sufficient innovation in the building industry compared to other industries has been criticized by many researchers (N. Wang, Xu, & Liu, 2023). The importance of innovation is evident in various fields of civil engineering, from building design to bridge construction. The industry requires innovation-based methodologies not only for design projects but also for the development of construction machinery, including 3D printers, cranes, robots, bulldozers, and more (Michaels, 2023).

2.2 Different Methods for Innovation

In the design process, there are several methods, including TRIZ (a Russian acronym for “Theory of Inventive Problem Solving”), Concept & Knowledge Theory (CK), General Design Theory (GDT), Axiomatic Design (AD), Coupled Design Process (CDP), and Infused Design (ID) (Salimi, 2022). The TRIZ theory has been a more systematic and beneficial design method since it was developed based on the analysis of more than 40,000 inventions.

2.3 TRIZ

Genrikh Saulovich Altshuller, who was famous as the creator of TRIZ, was an inventor before introducing this matrix. Altshuller's first invention certificate, which was for inventing an underwater diving apparatus, was received when he was in 9th grade. He had another invention in 10th grade. He had several other inventions as well, but his fame was not only due to them. In fact, he studied 200,000 inventions and identified 1,500 contradictions, which led to the development of 40 inventive principles (Figure 2.4) to solve these contradictions. These inventive principles became the key foundation of TRIZ. After that, he had several students

who worked on TRIZ and established TRIZ institutions in many cities to help inventors solve contradictions and introduce creative inventions in different fields (Lerner, 1991).

A contradiction occurs when a designer attempts to improve one feature, but it causes other features to worsen. The TRIZ Matrix includes a tool that recommends several inventive principles to help designers find innovative solutions to address this contradiction by improving one feature without worsening another targeted feature.

As illustrated in figure 2.1, a technical contradiction normally refers to a whole system's properties, like the contradiction between power and weight. What does it mean? It means that if someone wants a more powerful car or washing machine, they usually expect the weight of the vehicle or washing machine to increase as a worsening feature (Kraev, 2006).

What is the duty of TRIZ in solving such a contradiction? Actually, TRIZ recommends using IPs 8 (anti-weight), 36 (phase transitions), 38 (strong oxidants), and 31 (porous materials) to help the designer find an innovative solution to achieve more power (improving feature number 21 in TRIZ is 'power') for a car or laundry machine without increasing the weight of the car or laundry machine (worsening feature number 1 in the TRIZ matrix is 'weight of moving object') (Genrich Altshuller, Thierry Vilar, Unsplash, & Goguel, 2020).

Technical Contradictions (examples)	
Improving Parameter	Worsening Parameter
Power	Weight
Complexity	Functionality
Adaptability	Reliability
Productivity	Precision
Convenience of Use	Manufacturability

Figure 2.1 Some examples of technical contradictions
Taken from Kraev (2006)

TRIZ has 39 technical or engineering parameters (Figure 2.2). When an inventor wants to improve one parameter, other parameters could worsen during this function. TRIZ has forty inventive principles. In the TRIZ matrix, there are many intersections that show appropriate inventive principles to solve the contradiction. For example, according to TRIZ, if the inventor

considers “level of automation” as the improving feature and wants to avoid worsening “waste of energy,” then the TRIZ contradiction matrix recommends using principle number 23 (Feedback) or 28 (Replacement of a mechanical system) to solve the contradiction. It means the designer could find an innovative solution by using IP 23 or 28 to improve the “level of automation” without worsening the “waste of energy.”

Nº	Engineering Parameters	Nº	Engineering Parameters
1	Weight of a mobile object	21	Power
2	Weight of a stationary object	22	Loss of energy
3	Length of a mobile object	23	Loss of substance
4	Length of a stationary object	24	Loss of information
5	Area of a mobile object	25	Loss of time
6	Area of a stationary object	26	Amount of substance
7	Volume of a mobile object	27	Reliability
8	Volume of a stationary object	28	Accuracy of measurement
9	Speed	29	Accuracy of manufacturing
10	Force	30	Harmful factors acting on an object from outside
11	Tension / Pressure	31	Harmful factor developed by an object
12	Shape	32	Manufacturability
13	Stability of composition	33	Convenience of use
14	Strength	34	Repairability
15	Time of action of a moving object	35	Adaptability
16	Time of action of a stationary object	36	Complexity of a device
17	Temperature	37	Complexity of control
18	Brightness	38	Level of automation
19	Energy spent by a moving object	39	Capacity / Productivity
20	Energy spent by a stationary object		

Figure 2.2 TRIZ has 39 technical or engineering parameters
Taken from Naveiro and Oliveira (2018)

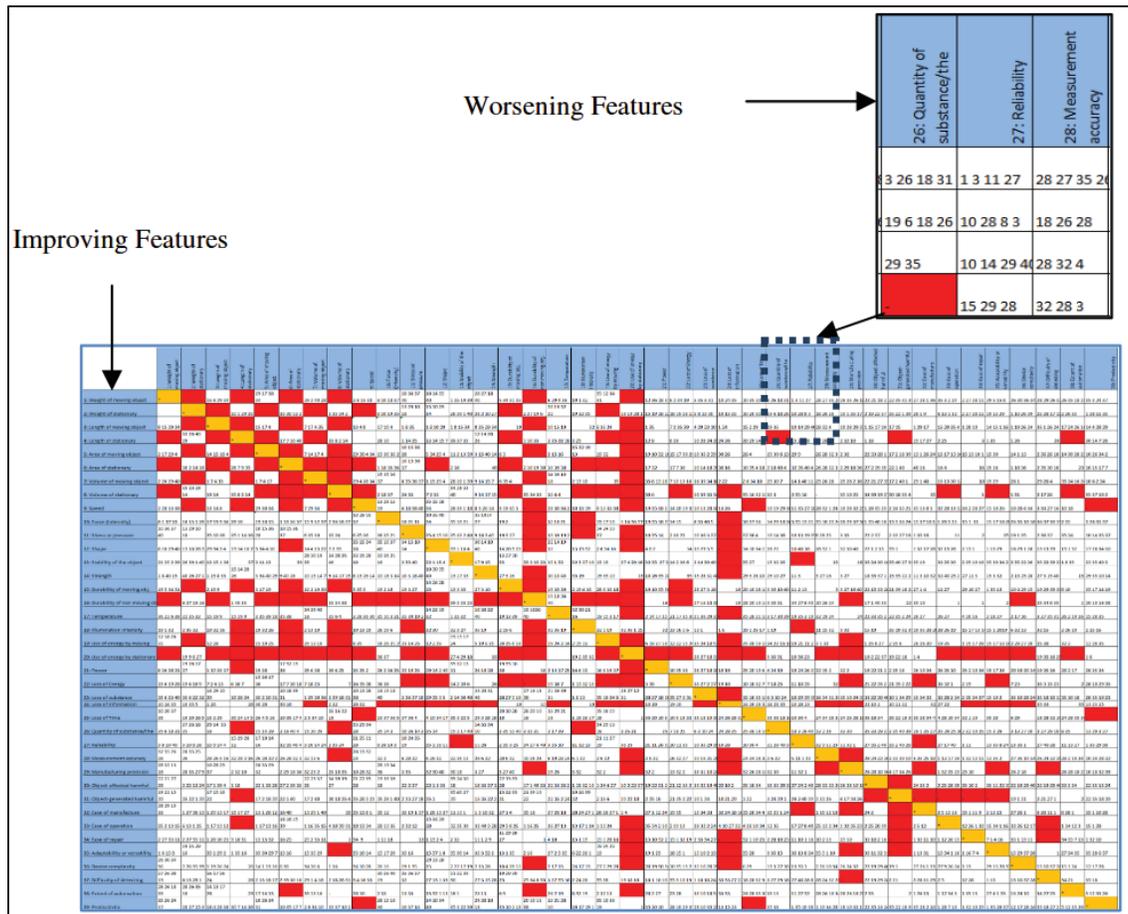


Figure 2.3 TRIZ Contradiction Matrix
Taken from Ang, Ng, Ahmad, and Wahab (2013)

TRIZ has 39 improving features and 39 worsening features. When one feature wants to be improved, another feature could be worsened. So, there could be a contradiction between the improving feature and the other worsening features. TRIZ introduces a few inventive principles for this kind of contradiction through its matrix tool to help designers find innovative approaches to improve one feature without worsening another feature.

Moreover, in traditional TRIZ, there are empty cells that are shown in red and orange in Figure 2.3. The red cells mean that TRIZ has not recommended any inventive principles (IPs) for that contradiction, while the orange cells are diagonal cells. In other words, the orange cells indicate that one parameter cannot have a contradiction with itself (Ang et al., 2013).

Nº	Inventive Principle	Nº	Inventive Principle
1	Segmentation	21	Rushing Through
2	Extraction	22	Convert Harm Into Benefit
3	Local Quality	23	Feedback
4	Asymmetry	24	Mediator
5	Consolidation	25	Self-service
6	Universality	26	Copying
7	Nesting	27	Dispose
8	Counterweight	28	Replacement of Mechanical System
9	Prior Counteraction	29	Pneumatic or Hydraulic Construction
10	Prior Action	30	Flexible Membranes or Thin Films
11	Cushion in Advance	31	Porous Material
12	Equipotentiality	32	Changing the Color
13	Do It in Reverse	33	Homogeneity
14	Spheroidality	34	Rejecting and Regenerating Parts
15	Dynamicity	35	Transformation of Properties
16	Partial or Excessive Action	36	Phase Transition
17	Transition Into a New Dimension	37	Thermal Expansion
18	Mechanical Vibration	38	Accelerated Oxidation
19	Periodic Action	39	Inert Environment
20	Continuity of Useful Action	40	Composite Materials

Figure 2.4 TRIZ Forty Inventive principles
Taken from Naveiro and Oliveira (2018)

In figure 2.4, each of the inventive principles could solve several contradictions in the TRIZ matrix. Each inventive principle has its own description. For instance, inventive principle number (IPN) one, called segmentation, could be recommended dividing one part into several parts to facilitate its disassembly (Genrich Altshuller et al., 2020). This could help designers to find an innovative approach to solve the appropriate contradiction.

Inventive Principle Number One (Segmentation) could resolve many contradictions, as listed below:

1/13, 1/18, 1/27, 1/32, 2/4, 2/13, 2/20, 2/29, 2/31, 2/32, 2/33, 2/36, 2/39, 3/11, 3/12, 3/13, 3/21, 3/24, 3/30, 3/32, 3/34, 3/35, 3/36, 3/37, 4/11, 4/16, 4/30, 4/35, 4/36, 5/30, 5/32, 5/34, 5/36, 6/10, 6/31, 6/36, 7/3, 7/5, 7/12, 7/13, 7/27, 7/31, 7/32, 7/36, 8/34, 8/36, 9/13, 9/28, 9/30, 9/32, 10/1, 10/2, 10/6, 10/20, 10/30, 10/32, 10/33, 10/34, 11/4, 11/32, 11/36, 12/13, 12/28, 12/30, 12/31, 12/32, 12/34, 12/35, 12/36, 12/38, 13/2, 13/3, 13/12, 13/17, 13/38, 14/1, 14/2, 14/3, 14/30, 15/32, 15/35, 16/4, 16/30, 16/33, 16/34, 16/38, 17/13, 18/1, 18/19, 18/20, 18/22, 18/23,

18/24, 18/25, 18/26, 18/35, 19/28, 19/30, 19/34, 20/32, 20/39, 21/3, 22/18, 22/33, 23/7, 23/18, 23/31, 24/3, 24/30, 25/18, 25/20, 25/34, 26/32, 27/12, 27/29, 27/34, 27/36, 27/39, 28/18, 28/27, 28/33, 28/34, 29/27, 29/33, 30/3, 30/4, 30/5, 30/12, 30/14, 30/16, 30/18, 30/19, 31/2, 31/6, 31/10, 31/12, 31/23, 31/25, 31/26, 31/36, 31/37, 32/2, 32/3, 32/5, 32/7, 32/9, 32/11, 32/12, 32/13, 32/14, 32/15, 32/18, 32/19, 32/20, 32/21, 32/26, 32/28, 32/34, 32/36, 32/37, 32/38, 32/39, 33/2, 33/3, 33/5, 33/7, 33/16, 33/18, 33/19, 33/29, 33/34, 33/35, 33/38, 33/39, 34/3, 34/8, 34/10, 34/12, 34/14, 34/16, 34/18, 34/19, 34/22, 34/25, 34/27, 34/32, 34/33, 34/35, 34/36, 34/39, 35/1, 35/3, 35/4, 35/12, 35/15, 35/18, 35/21, 35/22, 35/28, 35/32, 35/33, 35/34, 35/37, 36/3, 36/5, 36/8, 36/11, 36/27, 36/31, 36/32, 36/34, 36/38, 37/2, 37/7, 37/12, 37/21, 37/23, 37/35, 38/12, 38/13, 38/32, 38/33, 38/34, 38/35, 39/18, 39/20, 39/27, 39/28, 39/29, 39/33, 39/34, 39/35 (Genrich Altshuller et al., 2020). For instance, 1/13 means that if the worsening feature number 1, weight of moving objects, wants to be improved without deteriorating the worsening feature 13, stability of composition (according to Figure 2.2), Inventive Principle 1, Segmentation (according to Figure 2.4), could be one of the inventive principles that may help find an inventive solution to resolve the contradiction.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1 Weight of moving object	+		15, 8, 29, 34		29, 17, 38, 34		29, 2, 40, 28		2, 8, 15, 38	8, 10, 10, 36, 37, 40	10, 14, 35, 40	1, 35, 28, 27, 5, 34, 19, 39	6, 29, 4, 38	19, 1, 35, 12, 34, 31	12, 36, 18, 31	6, 2, 5, 35, 10, 24, 10								
2 Weight of stationary object		+		10, 1, 29, 35		35, 30, 13, 2		5, 35, 14, 2		8, 10, 13, 29, 19, 35	13, 10, 26, 39, 28, 2, 1, 40, 10, 27	2, 27, 28, 19, 19, 6	32, 22, 35	18, 19, 18, 19, 18, 22, 20, 15, 10, 15, 19	15, 19, 18, 19, 13, 30, 35, 35									
3 Length of moving object	8, 15, 29, 34		+		15, 17, 4		7, 17, 4, 35		13, 4, 8	17, 10, 4	1, 8, 35	1, 8, 35, 10, 29, 15, 34, 29, 34	19	8, 35, 24	1, 35, 35, 39, 23, 10, 1, 24									
4 Length of stationary object		35, 28, 40, 29		+		17, 7, 10, 40		35, 8, 2, 14		28, 10, 1, 14, 13, 14, 39, 37, 15, 14, 35	2, 38, 40	1, 10, 3, 35, 38, 18	3, 25	12, 8, 6, 28, 10, 28, 24, 35, 24, 26, 30										
5 Area of moving object	2, 17, 29, 4		14, 15, 18, 4		+		7, 14, 17, 4		29, 30, 19, 30, 10, 15, 5, 34, 11, 2, 3, 15, 6, 3	35, 2, 35, 28, 29, 4, 13, 39, 40, 14	2, 10, 35, 39, 19, 30, 38	2, 15, 15, 32, 19, 13	19, 10, 15, 17, 10, 35, 32, 18, 30, 29, 2, 39	19, 10, 15, 17, 10, 35, 32, 18, 30, 29, 2, 39										
6 Area of stationary object		30, 2, 14, 18		26, 7, 9, 39		+			1, 18, 10, 15, 35, 36, 36, 37	2, 38, 40	2, 10, 35, 39, 19, 30, 38	12, 8, 6, 28, 10, 28, 24, 35, 24, 26, 30	17, 32, 17, 7, 10, 14, 30, 18, 39	30, 16, 4, 10										
7 Volume of moving object	2, 26, 29, 40		1, 7, 4, 35		1, 7, 4, 17		+		29, 4, 15, 35, 6, 35, 1, 15, 28, 10, 9, 14, 1, 39, 15, 7, 6, 35, 4	11, 2, 28, 10, 1, 14, 13, 14, 39, 37, 15, 14, 35	34, 39, 2, 13, 10, 10, 18, 10	35	35, 6, 4, 30, 6, 7, 15, 36, 39, 13, 18, 13, 16, 34, 10, 10, 39, 34, 10	2, 22, 2, 34, 35, 35										
8 Volume of stationary object		35, 10, 19, 14		35, 8, 2, 14			+		2, 18, 37	24, 35, 7, 2, 35, 35, 40, 17, 15	35, 34, 38	35, 6, 4, 30, 6, 7, 15, 36, 39, 13, 18, 13, 16, 34, 10, 10, 39, 34, 10	30, 6, 7, 15, 36, 39, 13, 18, 13, 16, 34, 10, 10, 39, 34, 10	30, 6, 7, 15, 36, 39, 13, 18, 13, 16, 34, 10, 10, 39, 34, 10										

Figure 2.5 TRIZ Utility

In Figure 2.5, it has been illustrated how TRIZ could be used in resolving contradiction. If the designer wants to improve “length of moving object” without worsening “area of moving object,” then TRIZ is recommending the use of Inventive Principle numbers 15 (Dynamics),

17 (Another dimension), and 4 (Asymmetry) to resolve this issue by introducing innovative solutions inspired by IPN 15, 17, and 4.

TRIZ is an innovation methodology, but its direct application in the building industry is difficult. Therefore, there is a need to introduce a specific contradiction matrix that is useful in the building industry (Hassanijajini & Gardoni, 2022). This part of the literature review has been fully described and discussed in an article available in Chapter 3.

	QFD	TRIZ
CUSTOMER SATISFACTION	⊙	○
PRODUCT QUALITY	⊙	⊙
PROFITS	⊙	⊙
MARKET SHARE	⊙	⊙
INNOVATION	●	⊙
FAILURES ANTECIPATION		⊙
INTELLECTUAL CAPITAL PROTECTION		⊙
TECHNOLOGICAL PROSPECTION		⊙

○ WEAK IMPACT
● MEDIUM IMPACT
⊙ STRONG IMPACT

Figure 2.6 TRIZ could improve weak customer satisfaction by QFD
Taken from Naveiro and Oliveira (2018).

As it has been illustrated in Figure 2.6, TRIZ has weak capacity in considering all customer needs and weak ability to increase customer satisfaction. While QFD has a high capacity in taking voice of customer and consequently increases customer satisfaction. On the other hand,

TRIZ has the strong capacity for innovation by its strong tool, while QFD has not strong capacity like TRIZ in innovation. So, the utility of the TRIZ and QFD both together could improve innovation based on customer needs. Consequently, this trend could increase customer satisfaction and make the product saleable in the market (Naveiro & Oliveira, 2018).

2.4 QFD

2.4.1 Introduction of QFD

While TRIZ has the tools for resolving contradictions to help designers innovate a new approach or invention to overcome an issue and improve one technical contradiction without worsening another contradiction by using one or several IPs, its ability to capture the voice of the customer is weak. TRIZ could not get the customer's voice and give weight to each customer's priority to help designers and other decision-makers of the company improve production and increase the saleability of the product. So, several researchers recommended adding QFD to fulfill this gap (Al-Dwairi, Al-Araidah, & Hamasha, 2023; Bououchma & Herrou, 2023; Tursch, Goldmann, & Woll, 2015). QFD relies on two things: firstly, what does the customer need? And secondly, how could this need be achieved? To achieve this goal, the voice of the customer, through the QFD methodology, is categorized and prioritized by giving weight to them. In fact, when a contradiction happens, then TRIZ could be used as a creativity methodology through its 40 Inventive Principles to help designers tackle the problem by introducing creative solutions (Bououchma & Herrou, 2023). QFD could help customers by increasing customer satisfaction. It also helps designers to find out their priority in the design process. It also benefits entrepreneurs by showing unnecessary improvements that could increase the price too much and reduce customer satisfaction, by eliminating unnecessary improvements and reducing the time and cost of trial and errors before producing and examining in the real world to reduce the possibility of bankruptcy of the company (Tursch et al., 2015).

QFD was introduced in Japan to avoid a copy-paste approach and to improve the quality of production in manufacturing (Akao, 1997). From 1970 to 1972, QFD was developed in Japan, primarily at Mitsubishi's Kobe shipyard, a major shipbuilding firm. After fourteen years of

successful use in Japan, Ford and Xerox decided to buy its license for the USA in 1986. Recently, European industries have used QFD to reduce design costs and time by 60% and 40%, respectively. QFD has the ability to help designers hear the voice of the customer and create strong collaboration between Research and Development (R&D), sales teams, and manufacturing to capture and consider customer needs, in order to maximize the quality of production while considering cost and time reduction to achieve customer satisfaction and increase the sales capacity of the product (Hauser & Clausing, 1988; Hauser, Griffin, Klein, Katz, & Gaskin, 2010). QFD is a decision-making method that has been utilized by many designers and decision-makers. For instance, Hosam Elhegazy et al. have explained the utility of QFD in the construction industry, specifically for addressing owners' needs by owners and decision-makers (Elhegazy, Ebid, Mahdi, Haggag, & Abdul-Rashied, 2021).

QFD is a strategic methodology to consider customer's needs. In this methodology, some matrices called House of Quality (HOQ) are designed to prioritize customer's available options. HOQ helps designers by scoring and ranking design characteristics to choose the better option for each of the customer's needs to maximize customer satisfaction (Hauser et al., 2010; Salimi, 2022).

A manufacturer who did not use the QFD methodology had changed some components in the product line. The consequence of avoiding the use of a systematic decision-making method in this process was a gradual decrease in sales over several years. The company did not even know why the customers were gradually declining to buy that product. After that, the company was forced to use QFD by its R&D department to understand why the sales process had failed. Finally, identifying customer needs and systematic improvement through QFD was done. The results were surprisingly significant. The company, by moderate improvement of quality through distinguishing customer needs, successfully increased the number of sales of that product gradually and tackled the problem efficiently. (Erdil & Arani, 2019; Hauser & Clausing, 1988). These kinds of examples show that if someone wants to produce or invent a product, it is very important to consider customer needs. Since if the invention could not be commercialized, its sales percentage would decrease gradually, and finally, the company could go bankrupt. In a nutshell, it is important to use QFD after utilizing TRIZ or Archi-TRIZ to evaluate the product's saleability by considering customer needs to achieve customer

satisfaction (Caligiana, Liverani, Francia, Frizziero, & Donnici, 2017; Hauser & Clausing, 1988; Hauser et al., 2010). So, in this thesis, based on the above-mentioned information, it has been decided to use the QFD methodology after customized TRIZ to consider customer needs.

2.4.2 House of Quality (HOQ)

As illustrated in figure 2.7, HOQ has generally seven parts to combine customer's needs with engineering characteristic to choose the better parameters based on customer's needs and other limitations.

- 1- **Customer requirements:** The first part is gathering information regarding customer's needs. The customer's need could be described by potential customers that could state what they want to be added to the product and what are their priorities? This customer's interviews could be through personal interviews or gathering them in a small group of 5 to 10 people and make discussion and write a conclusion of their needs. In this stage, it is possible to get hundreds of customers needs but it is difficult to work with all these needs as a team. So, the second stage is categorizing, and distinguishing primary customers needs and structuring all secondary needs in a systematic manner. Normally, there are five to ten primary needs like "ease of use". Each primary need could be subdivided to several (three to ten) secondary needs. For instance, the primary or main need of "ease of use" could be subdivided as secondary needs like "easy to operate," "fast to use," "easy to set up." Since, they are describing ease of use in another language by more details. In some cases, secondary needs are also divided to tertiary needs. These could describe how the designers could design the product to fulfil the secondary needs. Here the discussion has been limited to primary and secondary needs (Erdil & Arani, 2019; Hauser & Clausing, 1988).
- 2- **Priority:** Customers like to fulfill all their requirements, but if a need is too expensive to meet, it could increase the price too much and lead to customer dissatisfaction, resulting in a decline in sales. So, the next task is to prioritize the important needs. Prioritization will help the QFD team evaluate the most important needs to moderate the price increase and maximize customer satisfaction while avoiding a decrease in

sales. Prioritizing customer needs could be done by market analysts through direct interviews with potential customers to ensure they are giving accurate scores to each customer need. Some companies use a one-to-one hundred scale, while others may use different scales, such as one-to-five or one-to-ten (Gharakhani & Eslami, 2012; Hauser & Clausing, 1988).

So, the first section of the HOQ presents the customer's primary, secondary, and tertiary needs in order of priority. The second section illustrates the importance rating assigned to each customer need.

- 3- Competitor analysis:** The third feature is competitor analysis, which shows how successfully each competitor addresses the customer requirements. This analysis also helps engineers identify which customer needs have not been fulfilled by competitors, enabling them to evaluate whether their product can address this gap without deteriorating other factors such as price or quality.
- 4- Design characteristics:** The voice of the engineer is the part that engineers should translate the voice of the customer to something measurable and designable for the design team. For instance, "the ease of use" could be translated to the designable factors like "initial setup time" and "the time of performing a task." These factors should be translated into the number of minutes that could be a target for engineers in the design team and could be reported to the R&D department of the company (Francis, 2016; Hauser & Clausing, 1988).
- 5- Relationship matrix:** The fifth room shows the relationship between customer requirements and design characteristics. In other words, this part determines which design characteristics may better satisfy the customer's needs (Erdil & Arani, 2019; Hauser & Clausing, 1988).

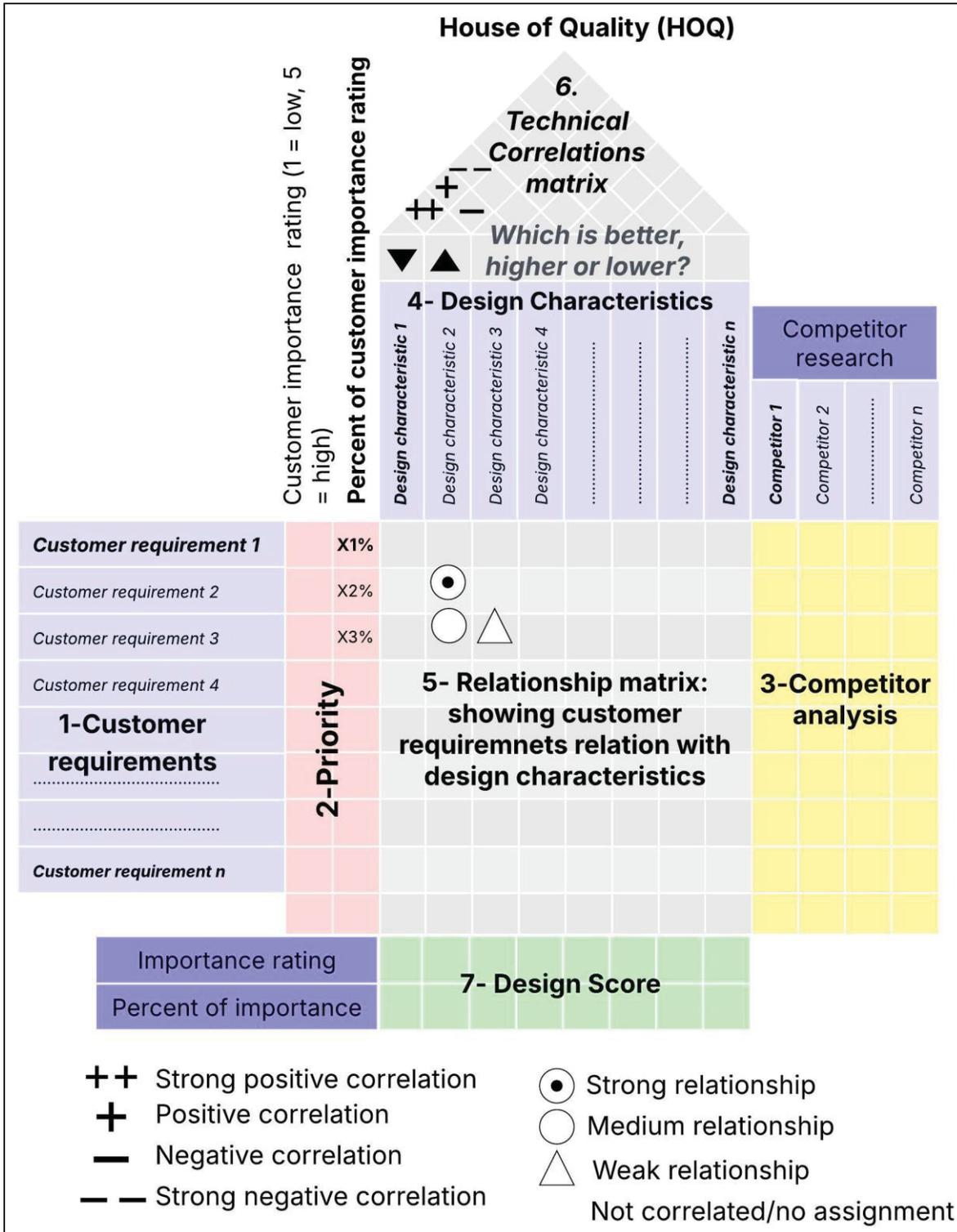


Figure 2.7 HOQ
 Adapted from: Francis (2016); Hauser and Clausing (1988).

6- Technical correlation matrix:

The roof of the HOQ is the technical correlation room. In this section, if we consider a printer as an example of the product, when a design characteristic like “speed of the print” in a printer increases, the other factor, such as “quality of the print,” could decrease dramatically. So, their correlation could be considered with two negative symbols. To resolve this contradiction, the design team could innovate a creative solution to improve both factors together. For simplicity, the roof of the HOQ, which handles technical correlations, has been removed in this thesis (Francis, 2016; Hauser & Clausing, 1988).

- 7- Design Score:** The importance rating and percent of the importance, to show the significance of a factor in comparison to other characteristics, could be calculated in the design score room. These scores show which design characteristic is more important in satisfying the customer's needs and requires more focus in the design process (Park & Kim, 1998; Salimi, 2022).

In a nutshell, it is very important to consider that the QFD methodology is a time-consuming process, requiring several feedbacks and collaborations between designers, customers, market analysts, and R&D departments. It could take several months to determine which characteristics are most important for customers and improve the product. However, its utility in the company significantly reduces the time and cost of the design process, as well as the back-and-forth of the design due to declines in sales and failures. Therefore, it is useful for being competitive in the market by utilizing QFD to satisfy customers and increase quality while focusing on important factors, eliminating unimportant and costly features, and improving the product’s saleability (Hauser & Clausing, 1988).

This literature review shows that TRIZ is a systematic innovation approach, but its direct application in building design is difficult. Therefore, a research gap has been identified, highlighting the need to develop a customized version of TRIZ. Moreover, it has been shown that using QFD could be useful for considering customer needs in the building design process. Chapters 7 and 8 include two articles that use QFD. In these articles, QFD is introduced and applied. For more clarification and information, it is recommended to read and refer to these chapters.

CHAPTER 3

THE IMPORTANCE OF PREPARING CUSTOMIZED TRIZ MATRIX TO ACCELERATE THE INNOVATION FOR DESIGN BUILDINGS

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3.1 Abstract

This paper shows that the lack of TRIZ implementation in the construction industry is significant. Establishing specialized contradiction matrices extracted from TRIZ could help the designer solve further innovative proto-types than standard TRIZ. In this trend, some of the principles are more serviceable and more meaningful than the other principles that persuade us to recommend and highlight this research gap. Numerous papers have been written about TRIZ, but a restricted number of these essays are about the construction industry; especially in architecture and building manufacturing. The suggestion is that presenting a detailed methodology for invention in the construction industry's architectural field is remarkable. This paper focuses on several papers' literature reviews that helped us find our research gaps and research problem. Utilizing TRIZ can escalate the construction process's technical innovations. The utility of TRIZ directly in the building design process is not easy. In some fields, researchers extracted Ecatriz from the original TRIZ, but Ecatriz is not practical in the building design process (Cherifi et al., 2019). So, establishing a customized contradiction matrix that has been extracted from the original TRIZ for building design is essential and valuable as a future work. Construction experts do not utilize formal or systematic design approaches in most cases. This circumstance results in several drawbacks (for a typical case, it is time consuming to discover an innovative and suitable solution). A systematic innovation approach could suggest to avoid such minuses that came out of TRIZ.

3.2 Introduction

TRIZ is the Theory of Inventive Problem Solving, a creative and innovative approach to problem-solving, which means problems can be solved by applying new ideas based on data and logic (Renev & Chechurin, 2016). Briefly, when an innovator wants to resolve a problem, he must procure an innovative approach to improve an element that will worsen another parameter. In other words, the inventor's innovatory solution has to endeavor to diminish or eliminate the worsening trend in another factor while improving one factor. Altshuller had several books, seminars, and articles, but he is famous because of his TRIZ contradiction matrix (Altshuller, 2003). Since 2000, There has been much research in different fields utilizing TRIZ to find inventive solutions. Based on SCOPUS, the percentage of papers in the construction field that includes the word TRIZ is about two percent out of all TRIZ papers in all fields. Therefore, the lack of innovation in the construction industry is obvious. Various articles have been investigated with the keyword TRIZ, but the primary challenge is that when the search has limited to the words: construction engineering, architectural engineering, and building among TRIZ articles, the quantity of articles dramatically decreases. Furthermore, this limited collection of articles has either done joint work between QFD and TRIZ or presented examples of the usefulness of TRIZ. However, none of them has done straightforwardly preparing a special matrix for architectural engineering. Oh, Cho, and Kim's article is the only paper that worked on a multi-piece wall panel (Oh, Cho, & Kim, 2017), which also did not work on specialized matrix. Rather, he has studied the exportable building that contains a segmented wall panel with the combined QFD and TRIZ methods, which also has differences from our proposed research. When numerous keywords have been examined, many articles have been founded, which have been supposed similar to current research in a glance, but the contrasts have been evidenced when the article's text has been read. Infact, there are a few papers like papers (Mann & Catháin, 2005; Potter et al., 2019), but they have not done a customized TRIZ contradiction matrix. The building and construction industry falls behind some other sectors (such as computers, IT, software, electronics, mechanical engineering, automotive industry, etc.) (Blayse & Manley, 2004; Cavallucci, 2009; Dale, 2007; Kulatunga, Amaratunga, & Haigh, 2006; Ozorhon, Abbott, Aouad, & Powell, 2010; Renev &

Chechurin, 2016). Innovation can be explained as “the successful exploitation of new ideas” (Dale, 2007; Renev & Chechurin, 2016). The modern building industry is eager to use inventive design rather than traditional approaches to be more flexible and competitive in the novel construction market. The significance of building industry organizations’ innovations is tremendous. Construction innovations can be appointed as a fourth dimension (4D) in the time ahead, parallel with the standard dimensions of time, cost, and quality. So, these companies could profit from market economy changes (Asad, Khalfan, & McDermott, 2006). Observing the research mentioned above proved the significance of current research.

3.3 Literature Review

3.3.1 Lack of TRIZ Implementation in the Construction Industry

TRIZ has not been used vastly in developing new techniques or production in the building industry. In other words, the lack of persistent and factual utility of TRIZ, an innovative approach to producing new products and designs, compared to its innate potential is significant (Abramov & Sobolev, 2019; Chechurin, 2016; Goldense, 2016; Leonid, Kalle, & Mika, 2015). Since 2000, There has been much research in different fields utilizing TRIZ to find inventive solutions.

Superior building artifacts must be innovative to be appointed as formidable on the market in performance, time, and cost-effectiveness. Furthermore, in a survey, 100% of respondents judged that innovation is pivotal for construction (Toole, 2001). There are innumerable surveys, research, and literature regarding innovation in building or structure, and approximately all of them announce that innovations are essential in the construction field. Nevertheless, the question is how someone can become innovative. Utilizing TRIZ can escalate the construction process’s technical innovations (Z. Ding & Ma, 2014).

Construction experts do not utilize formal or systematic design approaches in most cases. This circumstance results in several drawbacks (for a typical case, it is time consuming to discover an innovative and suitable solution). A systematic innovation approach has suggested avoiding

such minuses extracted from TRIZ. The procedure has 5 principles entitled “pillars”: contradiction, resources, function, interfaces, and ideality (C. Ó. Catháin & D. Mann, 2009).

3.3.2 Some Case Studies that Utilized TRIZ in the Construction Industry

The need for preparing specialized hypothesis for organizing innovation enhancement in the civil engineering field is obvious. Innovation is an essential side of the enrichment of construction techniques, but most procedures are based on the trial-and-error method. The Utility of TRIZ in discovering innovative solutions in construction has been done in some subjects like tunnel construction (Yasser Mohamed, 2002; Y Mohamed & AbouRizk, 2005). There are assorted articles in various construction fields, such as TRIZ in Evolution of Construction Techniques and Technologies (Altun, 2011; Altunb, 2012; Y. Lin & Lee, 2005), TRIZ in the Design of Construction Materials and New Structures (Dongkyu Lee & Shin, 2014, 2015; Yihong, Yunfei, & Ting, 2012), TRIZ in Value Engineering, and Construction Project Management (Cui, 2014; Moon, Choi, & Hong, 2016; J. Yang, Baeg, & Moon, 2014). However, a minimal number of them are relevant to our prospective research that I will particularly focus on them in the following chapters. Likewise, the innovation platform has been formulated by considering construction patents, and it gave more opportunities for obtaining inventive solutions in some sectors of this field (Z. Ding, Jiang, & Wu, 2014).

Several design theories such as C-K theory, Coupled Design Process, Axiomatic Design, General Design Theory, Infused Design, and TRIZ are available. Most of the theories are limited, which leads to inflexibility in the design process except for TRIZ and CK theory. TRIZ has principles for problem-solving and has special utility for our project. So, I choose TRIZ for our project. Ck theory is also an innovative design method, but it is needed knowledge and concept, and its knowledge is expanded during the design process. However, because CK theory could not solve our problem, we use TRIZ principles to solve our problem step by step. None of them except TRIZ has compared 40,000 inventions to produce a matrix such as a TRIZ contradiction matrix. TRIZ has forty inventive principles extracted from 40000 inventions and should lead to solutions, especially in our case studies.

3.3.2.1 Case Study 1: The Implementation of the Theory of Inventive Problem-Solving in Architecture

In this article, TRIZ has been utilized for constructing a building more accessible for individuals with disabilities. A tool developed by Kishinev School of Moldova, the Innovation Situation Questionnaire (IQS), has been used to subdivide the problem into subproblems. The Problem Formulation Process (PFP) and inventive principles (MIP) tools have also been used with the contradiction matrix to find possible inventive solutions. Ultimately, the novel TRIZ contradiction Matrix was utilized to obtain solutions (Kiatake & Petreche, 2012).

Table 3.1 Summarized Contradiction Matrix
Taken from Kiatake and Petreche (2012).

study			
FEATURE TO IMPROVE		UNDESIRE RESULT	
...	...	PR-13	PR-39
		STABILITY OF THE COMPOSITION	
PR-36	COMPLEXITY OF OBJECT	IP-2, IP-22, IP-17, IP-19	
PR-39	...		

As it has been illustrated in Table 3.1, the principles IP-22 (convert harm into benefit), IP-2 (extraction), IP-19 (periodic action), and IP-17 (moving to a new dimension) have been extracted from the Contradiction matrix TRIZ. From the aforementioned principles, two of them (IP-22, IP-17) guide to results.

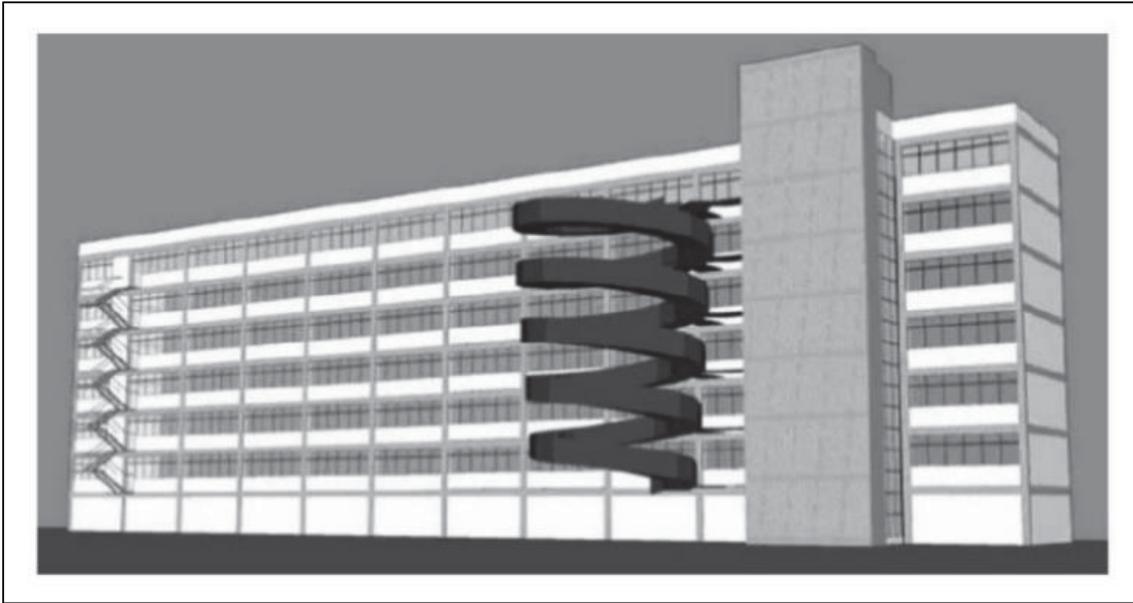


Figure 3.1 TRIZ, IP – 17 application in the footbridges
Taken from Kiatake and Petreche (2012).

In Figure 3.1, by inspiration from Principle IP-17, Spiral forms has been suggested for footbridge ramp (Kiatake & Petreche, 2012).

3.3.2.2 Case Study 2: Development of an Exportable Modular Building System by Integrating Quality Function Deployment and TRIZ Method

The purpose of this article is to examine Quality function deployment and the use of the TRIZ technique in the manufacturing business. These solutions are exceptionally efficient in reducing costs and enhancing quality. In contrast to the regular manufacturing process, manufacturing and exportable modular construction systems include several concurrent subprocesses. Therefore, there is a limit to the efficiency attained if one of these approaches is used straight to product development. To solve this issue, the authors propose a novel technique that combines TRIZ with the deployment of quality functions. According to the findings of a case study, it is feasible to lower the volume of an exportable modular construction system compatible with ISO container shipping by 48% and the weight of structural steel by 30 percent by using the new approach (Oh et al., 2017).

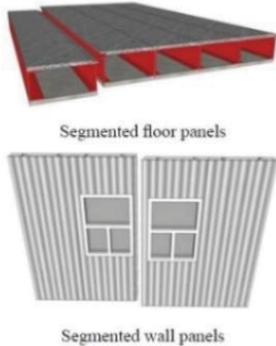
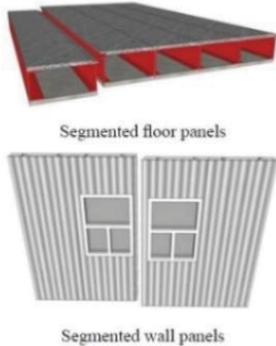
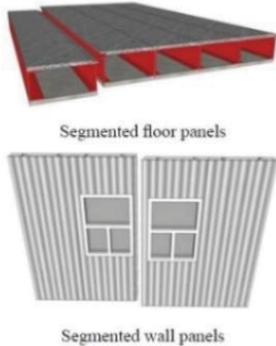
Table 10. Solution Derivation for F01-02					
Level 2 function	Form outside the module				
Level 3 functions	F01-2-A column, F01-2-B beam, F01-2-C Floor panel, F01-2-D Wall panel				
<p>"Principle 1: Segmentation": All components need not be delivered as a unit module. The building can be segmented into modules and non-modules. Components other than the modules are manufactured as columns, beams, floor panels, and wall panels. Modular units are offset stacked, with non-module components installed between modules.</p> <p>"Principle 31: Porous materials": Segmented components are loaded into other modules and delivered to the site. A modular unit is used as the porous material.</p>					
<table border="0" style="width: 100%;"> <tr> <td style="width: 50%; text-align: center;">Segmentation of floor and wall panels</td> <td style="width: 50%; text-align: center;">Load components inside other modules</td> </tr> <tr> <td style="text-align: center;">  <p style="text-align: center;">Segmented floor panels</p> <p style="text-align: center;">Segmented wall panels</p> </td> <td style="text-align: center;">  <p style="text-align: center;">Loading segmented components into other porous modules</p> </td> </tr> </table>		Segmentation of floor and wall panels	Load components inside other modules	 <p style="text-align: center;">Segmented floor panels</p> <p style="text-align: center;">Segmented wall panels</p>	 <p style="text-align: center;">Loading segmented components into other porous modules</p>
Segmentation of floor and wall panels	Load components inside other modules				
 <p style="text-align: center;">Segmented floor panels</p> <p style="text-align: center;">Segmented wall panels</p>	 <p style="text-align: center;">Loading segmented components into other porous modules</p>				
Design factors	<p>Design span between modules for site installation of panels shorter than 5 m.</p> <p>The size of panels is determined considering the possibility of loading inside the modules.</p>				

Figure 3.2 Segmented wall panels
Taken from Oh et al. (2017).

As it has been illustrated in Figure 3.2, on page 540 (JAABE vol. 16 no. 3 September 2017) in (Oh et al., 2017), the author (Seri Oh et al.) have used segmented wall panels for the Exportable Modular Building System, but it is just for transportable building design, and it is not what exactly we are going to do.

In Kiatake, M. and J.R.D. Petreche article, these following future works is mentioned:

- “1 - Case studies of MIP applications to completely new design projects;
- 2 - Case studies of other TRIZ tools with experimentation in the Architectural design field;
- 3 - Studies on the interface of the TRIZ methodology and multi-criteria decision-aid methods;
- 4 - Development of architectural knowledge databases and design of computational support tools;
- 5 - Creation of a structure of the TRIZ theory concepts for application in architectural design education” (Kiatake & Petreche, 2012).

These are the research gaps in TRIZ theory, precisely in the building and architecture industry, which shows our research problem and research gap. It is a worthwhile idea to adapt TRIZ to

the conservative field of study like Construction and do some investigations to verify its performance.

In this context, TRIZ would be applicable more straightforwardly in the construction industry. To support this proposition, we can declare some comparable case studies have been done in papers (Albers, Wagner, Kern, & Höfler, 2014; Gazem & Rahman, 2014a, 2014b; Pokhrel, 2013; C.-L. Yang, Huang, & Wei, 2013) in other fields such as Redesign Service, Process Engineering, Quality Improvement, Related Context, and Electric Energy Storage Systems.

3.3.2.3 Case Study 3, 4

In a thesis, the author gives a number of examples demonstrating the effectiveness of TRIZ in underground constructions. The majority of case studies have been derived from real-world circumstances, and it has been shown that TRIZ methodologies aid in achieving creative conceptual outcomes. On the basis of TRIZ, a design framework for the technological innovation platform has been suggested by using patent knowledge in construction projects. Some of the TRIZ concepts have not been used at all, whilst others have been used repeatedly (Yasser Mohamed, 2002).

After 3 years, the same author justified the advantage of TRIZ and its serviceableness in the Construction tunnel industry. Moreover, he did not consider the most suggestive principles in a customized new contradiction matrix to accelerate tunnel construction innovation by this methodology (Yasser Mohamed, 2002; Y Mohamed & AbouRizk, 2005) (Table 3.2).

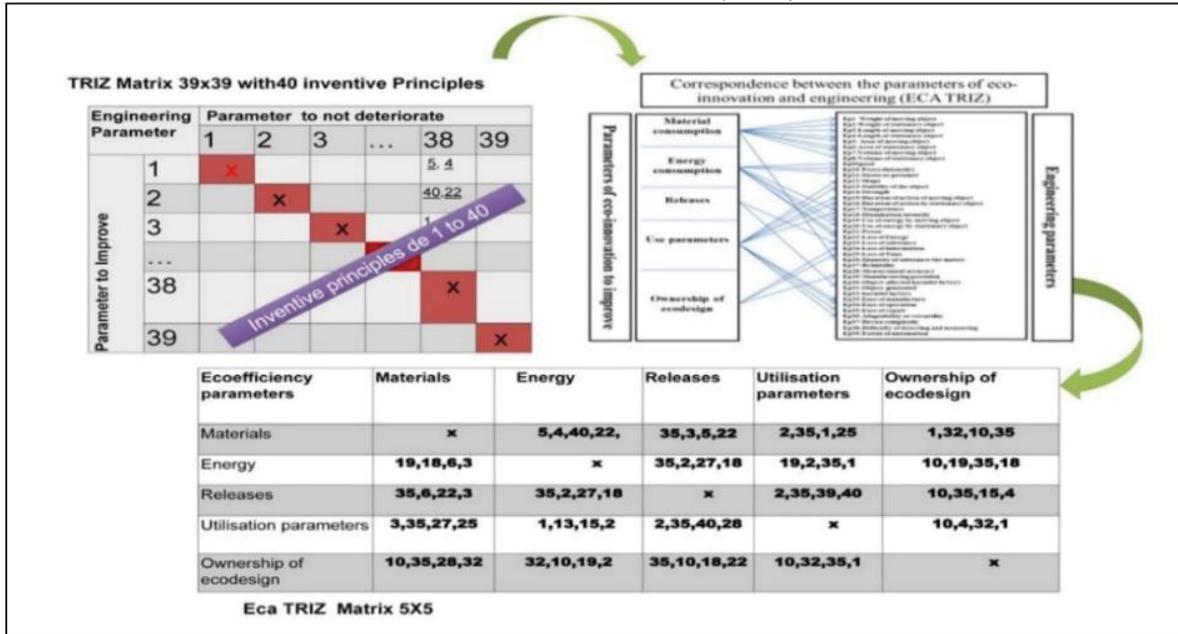
Table 3.2 Contradiction matrix sample
Taken from Y Mohamed and AbouRizk (2005).

Engineering Parameters		Parameter that is getting worse					
		27	28	29	30	31	
		Reliability	Accuracy of Measurement	Accuracy of Manufacturing	Harmful factors acting on object from outside	Harmful factors developed by an object	
Parameter to be improved	23	Loss of Substance		35, 10, 24, 31			
	24	Loss of Information					
	25	Waste of Time	10, 30, 4	24, 34, 28, 32	24, 26, 28, 18	35, 18, 34	35, 22, 18, 39
	26	Amount of Substance		33, 30			
	27	Reliability	Physical Contradiction		11, 32, 1		
	28	Accuracy of Measurement		Physical Contradiction	-		
Resolution Principles		23) Feedback 24) Intermediary 25) Self-service		26) Copying 27) Inexpensive short-lived objects 28) Mechanics substitution			

3.3.2.4 Case Study 5

Ecatriz has been suggested as a methodology to resolve some contradictions in eco-design. This methodology aims to aid small and medium-sized enterprises (SMEs) in developing products that will enable them to reach their eco-innovative goal. A qualitative matrix will enable the prioritization of all environmental impacts. Implementing the creative TRIZ principles on an individual basis will aid the researcher in selecting eco innovative solutions. Based on an original contradiction matrix, a unique technique called Ecatriz (ecology-friendly approach TRIZ) has been developed. It has been studied in various situations, including the “24 h of Innovation” competition and eco-innovative patents (Cherifi et al., 2019) (Table 3.3).

Table 3.3 The approach to obtaining the Ecatriz matrix
 Taken from Cherifi et al. (2019).



Based on these researches, we found that producing the customized contradiction matrix as the methodology in the architectural building design process with moveable walls would be a fascinating research gap that we can fill and add value to this field in the future.

3.4 Result

Previous surveys have concentrated on the efficacy of TRIZ in design various construction industries slightly and not on How to operate TRIZ to consider better the different customer needs base on considering customer elections by utilizing various architectural plans in the same apartment. TRIZ is one of the essential tools in the innovative design process. Especially for decreasing the cycles of design that is required to finalizing the architectural plan design process.

In other words, there are so many varied architectural plans that can be drawn for a unique apartment. How could we suggest an approach or tool that can provide different plans faster during the life cycle without wasting too much budget and time in renovating the apartment based on the new tenant’s preferences? Consequently, this will diminish the price of the

nonessential renovation of a building for interchanging its plan. The specialize matrix that could extracted from TRIZ could help the designers to accelerate the process of innovation in their design process.

3.5 Conclusion

Using TRIZ matrix in the building design process, the first challenge is that the plans produced right now by computer programs like Revit cannot consider all the needs of customers perfectly. More over, when the property owner wants to rent out one apartment to a tenant. There are several choices for a tenant. Some tenants prefer a one-bedroom apartment rather than two bedrooms. Some others prefer to rent out two bedrooms or a studio without a bedroom, thinking about the problems and their possible solutions through the contradiction matrix Altshuler is significant. The main objective is to prepare and fulfill table by its 7 steps and prepare a specific contradiction matrix extracted from the original TRIZ contradiction matrix to accelerate the design process with more inventive solutions in the upcoming paper.

3.6 Future Works

As a future work, we will fulfill Customized Matrix and choose the most repetitive and relevant TRIZ principles to put in every part of this Matrix. Therefore, we hope that the work will become more specific, and fascinating results will be achieved by completing the specific contradiction matrix extracted from the original TRIZ matrix for building design process.

CHAPTER 4

RESEARCH METHODOLOGY

4.1 Introduction

This chapter included four different phases of this PhD thesis methodology. The methodology is an important part of research process. It is essential to choose a well-organized and practical methodology to achieve reliable results (Bahishti, 2022).

4.2 Research Methodology

This PhD thesis has four different phases, as mentioned below:

- Phase 1. Theoretical study to to choose an appropriate design methodology
- Phase 2. Framework Specialization :Specializing chosen design methodology to produce specialized contradiction matrix
- Phase 3. Methodology Expansion :Adding some civil engineering examples to the specified design methodology.
- Phase 4. Decision Framework Development and Design Optimization: Choosing a method for decision making in design process and fulfil the gap of specific contradiction matrix and add more details to the outcome of designed object.

These are the thesis phases that ensure valid and practical outcomes. In the following parts, each phase has been explained.

4.2.1 Phase 1: Theoretical study to choose an appropriate design methodology

The aim of the first phase (theoretical study to choose an appropriate design methodology) was to select a suitable design methodology. In fact, the first article, which is presented in Chapter 3, is dedicated to this phase. A variety of journal articles, research papers, and conference papers from different sources such as Scopus and Google Scholar were downloaded and read to identify the research gap. The comparison of these articles led to the conclusion that introducing and developing a customized contradiction matrix based on TRIZ for building non-structural components is a valuable research gap. This topic is addressed in the next article, which appears in Chapter 5.

4.2.2 Phase 2. Framework Specialization :Specializing chosen design methodology to produce specialized contradiction matrix

The aim of the second phase was the preparation of the Archi-TRIZ Matrix for accelerating innovation in the building design process, especially for non-structural components of buildings. In this phase, first, the 39 technical contradictions of the original TRIZ were combined and categorized under new names, resulting in 7 technical contradictions in Archi-TRIZ. Then, 7 different tables were produced. All of the contradictions were considered, and the most repetitive and inspirational ones were selected and included in Archi-TRIZ. In article two, which is available in Chapter 5, only 2 out of the 7 tables are presented. The remaining 5 tables are illustrated in the appendix as Steps 3 to 7 of preparing Archi-TRIZ. Therefore, it is recommended to refer to them to gain more insight into the core methodology of the thesis.

4.2.3 Phase 3. Methodology Expansion :Adding some civil engineering examples to the specified design methodology.

The aim of the third phase of the thesis, which is presented in the third article in Chapter 6, was to expand the thesis methodology through two main actions. First, several papers were downloaded from sources such as Google Scholar, Scopus, etc., and reviewed. Relevant articles, innovative designs, and creative approaches that could be useful in various civil

engineering and building design projects were identified. Descriptions were added, and the content was logically connected to each of the 40 inventive principles of the Archi-TRIZ methodology, resulting in the creation of several tables. Second, examples from these tables—each linked to a specific inventive principle—were later recommended to be included in a website or even a mobile application, with the goal of accelerating innovation in the building design process by facilitating brainstorming for designers and civil engineers.

4.2.4 Phase 4. Decision Framework Development and Design Optimization: Choosing a method for decision making in design process and fulfil the gap of specific contradiction matrix and add more details to the outcome of designed object.

The aim of Phase 4 is to introduce a decision-making method that could help designers choose better options derived from Archi-TRIZ, while also adding more features to the product by considering customers' needs. To achieve this aim, several articles from different sources were downloaded and reviewed, and QFD was chosen as the decision-making methodology. QFD was then utilized after applying Archi-TRIZ to add more features to the movable wall example, first to choose the better option between two alternatives, and then to add more features based on customers' needs. This process was carried out using QFD in the fourth and fifth articles. In summary, the methodology was applied twice to achieve better results in Chapters 7 and 8. Therefore, it is recommended to refer to and read Chapters 7 and 8 for more information on this. Additionally, the QFD from Chapters 7 and 8 is illustrated in a larger size in the appendix for the reader's convenience.

CHAPTER 5

PREPARATION OF ARCHI-TRIZ MATRIX FOR ACCELERATING INNOVATION IN BUILDING DESIGN PROCESS

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5.1 Abstract

TRIZ (a Russian acronym for “Theory of Inventive Problem Solving”) is an important design approach, but its direct application to building design is complicated. The primary purpose of this study is to prepare Archi-TRIZ to accelerate innovation in the design process of building non-structural components. In the Methodology section, the creation process of Archi-TRIZ has been described. In the original TRIZ, there were thirty-nine improving and worsening features. These features have been converted to seven features in Archi-TRIZ in seven steps. First, it has been considered that if a building’s non-structural component (BNSC) dimensions and physical characteristics were improved, what would be the worsening features? It has been discovered that speed and time, strength and stability of the BNSC, etc., could be worsening features. Then, the most repetitive inventive principles were ranked and chosen to be put in Archi-TRIZ from the original TRIZ. A designer using Archi-TRIZ could utilize inventive principles to improve one feature without worsening another feature to solve the contradiction and could improve the design of BNSC by innovative approaches. Some examples have been prepared to examine the applicability of the Archi-TRIZ in designing BNSC. TRIZ has been used in different fields of study, but there needs to be more study in the construction industry compared to other fields. There is a need to introduce new methodologies for accelerating innovation in building design. There is no customized TRIZ contradiction matrix in design building fields. Therefore, this research gap could be filled by Archi-TRIZ and other methods.

5.2 Introduction

The TRIZ (a Russian acronym for Teoriya Resheniya Izobretatelskikh Zadach, which means “Theory of Inventive Problem Solving”) method provides a process for discovering solutions and predicting innovation. Innovators aiming to tackle a problem can introduce novel approaches that improve one parameter while worsening another. Applying inventive solutions can reduce the severity of worsening features (Altshuller, 2003; Renev & Chechurin, 2016). Since 2000, there has been a great deal of study in several disciplines using TRIZ to create innovative approaches. According to SCOPUS, just 2 percent of all TRIZ papers are in the construction industry. Accordingly, it shows a need for more innovation in this field. Additionally, this restricted collection of publications either combines TRIZ and QFD (Quality Function Deployment) or provides cases of TRIZ’s use in various areas. Despite this, they still need to prepare a clear matrix for architectural engineering that can be used as a guide to accelerate innovation as a methodology in the design process. Regarding multipiece wall panels, the only researchers who worked on them were Potter et al. (Oh et al., 2017; Potter et al., 2019). In fact, Oh, Cho, and Kim (2017) explored an exportable structure with a segmented wall panel using a combination of QFD and TRIZ (Oh et al., 2017), which is entirely different from our suggested study. Many articles that initially seem comparable to our research are discovered when analyzing many keywords. However, significant differences are revealed when the article’s content is read. Based on my searches, I found a few articles, but they have not created a TRIZ contradiction matrix as a result. Regarding ranking TRIZ utility in all fields, the construction and building sector lags behind other industries like IT, computer, software, automotive, mechanical engineering, electronics, etc. (Blayse & Manley, 2004; Cavallucci, 2009; Dale, 2007; Kulatunga et al., 2006; Ozorhon et al., 2010; Renev & Chechurin, 2016). In the future, innovations in the building industry are likely to be considered a fourth dimension. Therefore, innovation would be the fourth important factor after time, cost, and quality. Thus, these businesses might benefit from market economic adjustments (Asad et al., 2006). The previous paper demonstrates the importance of existing scientific studies (Hassanijajini & Gardoni, 2022).

5.3 Literature Review

Many studies, surveys, and publications have been conducted about innovation in the construction industry. Almost all of them assert that innovation is crucial to the industry's success. Despite this, the question for an individual is how they can become inventive (Z. Ding & Ma, 2014).

It has been stated in some articles that construction designers did not use systematic design approaches in many cases. This causes several problems like the time-consuming process for inspiring building designers. The new approach, which is based on five principles, including “contradiction, resources, functionality, interfaces, and ideality,” has been introduced to tackle this lack of systematic design procedure. They called this method “pillars” (D. C. Ó. Catháin & D. Mann, 2009; Renev & Chechurin, 2016). The construction industry does not use TRIZ to its full potential. It is essential that specific hypotheses are needed for the emergence of creativity enhancement in the field of civil engineering. Innovation is vital to improving building processes, although many operations involved in the construction industry are based on trial-and-error methods. TRIZ has been used in several fields, including tunnel construction, the evolution of construction techniques and technologies, futuristic structures and novel construction materials, value engineering projects, and the management of construction projects. It has been applied to the discovery of innovative solutions in construction (Altunb, 2012; Coşkun & Altun, 2011; Cui, 2014; Dongkyu Lee & Shin, 2014, 2015; Y. Lin & Lee, 2005; Yasser Mohamed, 2002; Y Mohamed & AbouRizk, 2005; Moon et al., 2016; J. Yang et al., 2014; Yihong et al., 2012). Nevertheless, only a few of these issues will significantly impact our future study. Moreover, it has been suggested that establishing an innovation platform for this industry increases the possibility of getting creative ideas. This will increase the likelihood of getting patents in specific sectors of this industry (Z. Ding et al., 2014).

The field of innovative design has a variety of design concepts, including Coupled Design Process, CK theory, Axiomatic Design, Infused Design, General Design theory, and TRIZ theory. Many theories are constrained, resulting in inflexibility in the design process. Our research benefits significantly from TRIZ's problem-solving ideas. Innovative design

strategies like CK theory need information and concepts developed during the design phase, while TRIZ inspires you to create inventive design ideas before starting the design phase. Since “TRIZ” consists of forty concepts derived from 40,000 inventions, which should lead to inventive solutions, there has been no comparison with TRIZ.

Small and medium-sized businesses (SMEs) can benefit from Eca-TRIZ by generating eco-friendly products to meet their customers’ needs. Using a qualitative matrix can rank all environmental consequences in importance. Researchers can identify eco-innovative alternatives by applying the creative TRIZ principles on a case-by-case basis while using the TRIZ principles individually. The concept has been examined in various situations, such as the “twenty-four hours of innovation” event and eco-friendly patented products (Cherifi et al., 2019; Hassaniyajini & Gardoni, 2022).

It has been concluded that generating a specified contradiction matrix would be a valuable approach to designing buildings. This matrix is derived from the original TRIZ to speed up innovations in building design. This customized matrix is named Archi-TRIZ. After that, its applicability will be examined by some examples explained in the following sections (Hassaniyajini & Gardoni, 2022).

5.4 Methodology

5.4.1 How to Create Archi-TRIZ

This matrix was extracted from the original TRIZ contradiction matrix through seven steps as part of our project’s process. Initially, a summary matrix was extracted from the TRIZ matrix in seven steps, but due to space limitations, only two parts have been included here. Table 5.1 provides a better understanding. The steps of creating Archi-TRIZ have been summarized in Figure 5.1.

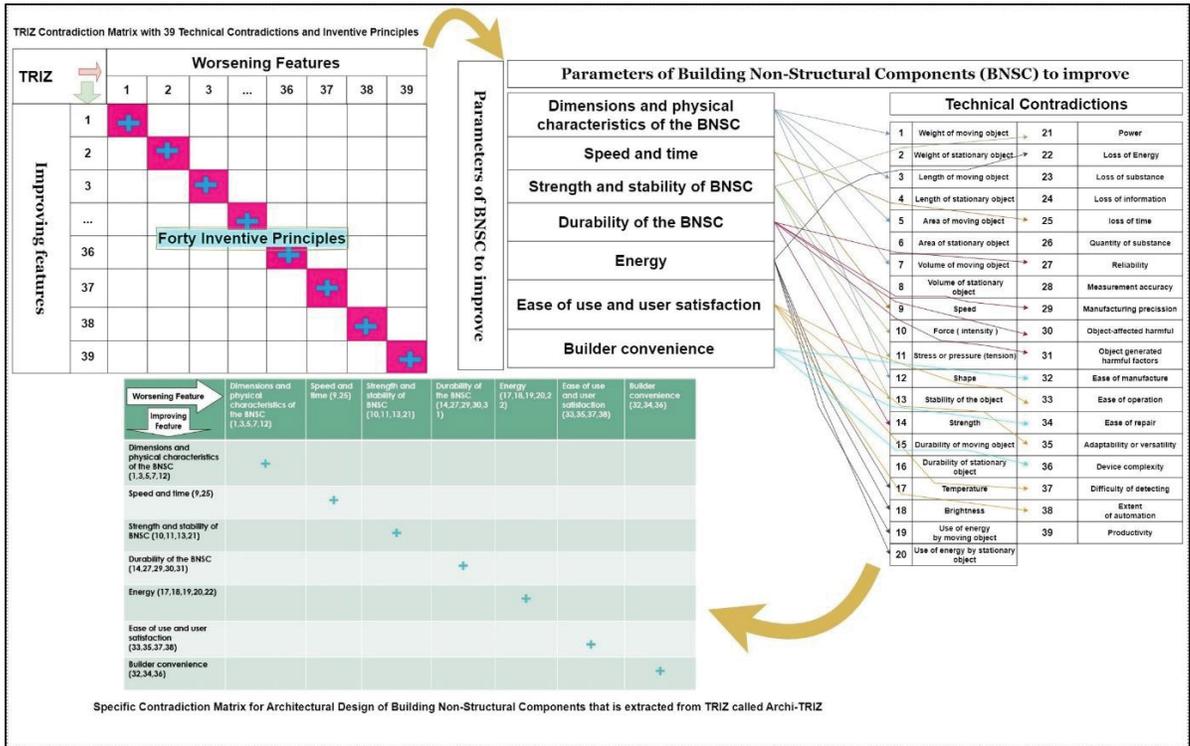


Figure 5.1 Steps of Creating Archi-TRIZ

Table 5.1 Step 1 of Preparing Archi-TRIZ Matrix

Worsening Feature	Dimensions and physical characteristics of the BNSC (1,3,5,7,12)	Speed and time (9,25)	Strength and stability of BNSC (10,11,13,21)	Durability of the BNSC (14,27,29,30,31)	Energy (17,18,19,20,22)	Ease of use and user satisfaction (33,35,37,38)	Builder convenience (32,34,36)
Improving Feature							
Dimensions and physical characteristics of the Building non-structural component (BNSC) (1,3,5,7,12)	+	2, 8, 15, 38 13, 4, 8 29, 30, 4, 34 29, 4, 38, 34 35, 15, 34, 18 = 34,29,38	8,10,18,37,10,36, 37, 40,1, 35, 19, 39,12, 36, 18, 31 = 10,18,36,37 17, 10, 4,1, 8, 35, 1, 8, 15, 34, 1, 35 = 1,8,35 19, 30, 35, 2 10, 15, 36, 28 11, 2, 13, 39 19, 10, 32, 18 = 10,19,2 15, 35, 36, 37 6, 35, 36, 37 28, 10, 1, 39 35, 6, 13, 18 = 35,36,37 35, 10, 37, 40 34, 15, 10, 14 33, 1, 18, 4 32, 35, 27, 31 = 10,35,33,31	28, 27, 16, 40, 8, 35, 29, 34, 3, 15, 40, 14, 9, 14, 15, 7, 30, 14, 10, 40 1, 3, 11, 27, 10, 14, 29, 40 29, 9, 14, 1, 40, 11, 10, 40, 16 = 40,14,29,11,9 28, 35, 26, 18, 10, 28, 29, 37 2, 32, 25, 28, 2, 16, 32, 30, 40 = 28,32 22, 21, 18, 27 1, 15, 17, 24 22, 33, 28, 1 22, 21, 27, 35 22, 1, 2, 35 = 22,1,21,27,35,33 22, 35, 31, 39, 17, 15, 17, 2, 18, 39, 17, 2, 40, 1, 35, 1 = 17,1,2,35,39,(30,31)	6,29,4,38,10,15, 19,2,15,16,34, 39, 10, 18, 22, 14, 19, 32 = 10,15,19,38 19, 1, 32, 32, 15, 32, 19, 13, 2, 13, 10, 13, 15, 32 = 32,13,19 35, 12, 34, 31, 8, 35, 24, 19, 32, 35, 2 , 6, 34, 14 = 35,34 6, 2, 34, 19, 7, 2, 35, 39, 15, 17, 30, 26, 7, 15, 13, 16, 14 = 2,7,15,39	35, 3, 2, 24, 15, 29, 35, 4, 15, 17, 13, 16, 15, 13, 30, 12, 3 2, 15, 26 = 15,13,35 29, 5, 15, 8, 14, 15, 1 , 16, 15, 30, 15, 29, 1 , 15, 29 = 15, 29, 1 28, 29, 26, 32, 35, 1, 26, 24, 2, 36, 26, 1 8, 29, 26, 4, 15, 13, 39 = 26, 29 26, 35 18, 19, 17, 24, 26, 16, 14, 30, 28, 23, 35, 34, 16, 24, 15, 1, 32 = 26, 35, 24, (30, 14)	27, 28, 1, 36, 1, 29, 17, 13, 1, 26, 24, 29, 1, 40, 1, 32, 17, 28 = 1, 28 2, 27, 28, 11, 1, 28, 10, 15, 13, 10 , 1, 10, 2, 13, 1 = 1, 10, 2, 28, 13, 11 26, 30, 36, 34 1, 19, 26, 24, 14, 1, 13, 26, 1, 16, 29, 1, 28 = 1, 26

As a first step (Table 5.1), it has been considered what would be the worsening features of a building's non-structural component (BNSC) if its dimensions and physical characteristics were improved. It has been discovered that speed and time, strength and stability of the BNSC, durability, energy, ease of use, user satisfaction, and builder convenience could be worsening features. A designer using Archi-TRIZ would employ inventive principles to improve one feature without worsening another. For instance (Figure 5.1), as a result of increasing the dimensions and physical characteristics of the BNSC, the energy would be one of the worsening features. In the energy column, features no. 17, 18, 19, 20, and 22 refer to temperature, illumination intensity, energy used by moving objects, the use of energy by stationary objects, and loss of energy in the original TRIZ.

The numbers under the column titled "energy" in Table 5.1 need to be explained in detail. In line 1 of the column energy in the original TRIZ, the first row and column 17 shows that principle number 6, 29, 4, and 38 have been recommended to resolve the contradiction. In Table 5.1, they have been written in the first line under the "Energy" column. As a result of the intersection between row 3 and column 17 in TRIZ, inventive principle numbers 10, 15, and 19 have been obtained from the original TRIZ and written in the "Energy" column of the first table of our matrix. All the principles were transferred into the column in the same manner. The most repetitive and inspirational principles have been highlighted as the next step. Several innovative TRIZ principles have been used to help us develop creative solutions to resolve this contradiction. All those solutions were written from TRIZ without neglecting them under our matrix's "Energy" row.

As the next step, more important factors have to be selected in two stages. Before ranking all the principles, their repetition is considered. Inventors need flexible ideas to find new solutions. Some of the less repetitive principles examined in the table were inspirational, so we decided

to place just a few less repetitive principles in parentheses that were still inspirational after the most repetitive principles.

Table 5.2 Step 2 of Archi-TRIZ Matrix

<div style="text-align: center;">  Worsening Feature </div> <div style="text-align: center;">  Improving Feature </div>	Dimensions and physical characteristics of the BNSC (1,3,5,7,12)	Speed and time (9,25)	Strength and stability of BNSC (10,11,13,21)	Durability of the BNSC (14,27,29,30,31)	Energy (17,18,19,20,22)	Ease of use and user satisfaction (33,35,37,38)	Builder convenience (32,34,36)
Speed and time (9,25)	2,28,13,38,13,14,8,29,30,34,7,29,34,35,15,18,34= 34,13,29,7,38	+	13,28,15,19,6,18,38,40,28,33,1,18,19,35,38,2 = 38,19,28,33	8,3,26,14,11,35,27,28,10,28,32,25,1,28,35,23,2,24,35,21 = 35,28,11	28,30,36,2,10,13,19,8,15,35,38,14,20,19,35 = 35,19,20	32,28,13,12,15,10,26,3,3,4,27,16,10,1 8= 10,18,32	35,13,8,1,34,2,28,27,10,28,4,34 = 28,34
	10,20,37,35,15,2,29,26,4,5,16,2,5,34,10,4,10,34,17 = 10,34,4,5,20		10,37,36,5,37,3,6,4,35,3,22,5,3,5,20,10,6= 37,35,36,5,20	29,3,28,18,10,30,4,24,26,28,18,3,5,18,34,35,22,18,39= 18,28,35	35,29,21,18,1,19,26,17,35,38,19,18,1,10,5,18,32 = 18,1,35,38	4,28,10,34,3,5,28,18,28,3,2,10,24,28,3,5,30= 28,35,10	35,28,34,4,32,1,10,6,29 = 35,1,4,10

Like step 1 in Table 5.1, a similar process has been used in the second step (Table 5.2) to select the most repeated, practical, necessary, and inspiring inventive principles. In the TRIZ diagram, row 9 corresponds to speed, and row 25 corresponds to time lost. In other words, the loss of time is another expression of speed since when you do not wish to lose time, you must

speed up the process. Therefore, they belong to the same category. Both elements are placed in the same vacant space in our Archi-TRIZ matrix.

Table 5.3 Archi-TRIZ Matrix for building non-structural components design process

<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="text-align: center;"> <p>Worsening Feature →</p> <p>← Improving Feature</p> </div> <div style="text-align: center;"> <p>Dimensions and physical characteristics of the BNSC (1,3,5,7,12)</p> </div> <div style="text-align: center;"> <p>Speed and time (9,25)</p> </div> <div style="text-align: center;"> <p>Strength and stability of BNSC (10,11,13,21)</p> </div> <div style="text-align: center;"> <p>Durability of the BNSC (14,27,29,30,31)</p> </div> <div style="text-align: center;"> <p>Energy (17,18,19,20,22)</p> </div> <div style="text-align: center;"> <p>Ease of use and user satisfaction (33,35,37,38)</p> </div> <div style="text-align: center;"> <p>Builder convenience (32,34,36)</p> </div> </div>							
Dimensions and physical characteristics of the BNSC (1,3,5,7,12)	+	29,10,8,15,20,38	10,35,1,(18,36,37,33,21,31)	40,1,35,(14,28,22,2,33,39,9,30,7,11,31)	15,19,32,2,(34,35,39,7,31,38)	15,26,29,(35,1,24,30)	1,28,13,26,(11)
Speed and time (9,25)	34,29,10,2,(13,4,5,35,20,7,38)	+	35,6,(5,10,19,28,36,37,38,20,33)	35,28,18,(3,24,26,11)	35,19,18,1,(5,20,38)	28,10,(18,32,34,35)	28,34,(1,4,10,35)
Strength and stability of BNSC (10,11,13,21)	10,35,15,36,(31,9,11,38)	35,36,15,(10,28,37,6,20,33)	+	35,27,18,2,(9,11,33)	2,10,14,16,(19,35,(25,38)	35,2,17,19,(30,20,11)	35,10,1,(2,19,26,20,11)
Durability of the BNSC (14,27,29,30,31)	1,10,15,22,35,40,(8,4,9,7,23,30,11,33)	28,35,10,(3,18,21,22,26,32,11)	35,18,2,10,3,28,(30,11,31,33)	+	35,2,19,32,10,22,(24,21,11,33)	27,40,2,(3,15,32,35,25,23,11,31,33)	2,1,10,11,35,(25,31)
Energy (17,18,19,20,22)	19,18,32,15,(2,6,12,13,28,7,30,31)	35,18,19,(10,28,38,7)	19,2,32,35,21	35,2,19,22,3,1,21,33	+	35,2,19,(15,26,31)	28,2,16,17,26,7
Ease of use and user satisfaction (33,35,37,38)	1,13,15,17,35,(16,28,29,7)	28,35,10,(4,34)	35,30,2,(1,28,32,20,39)	28,32,2,27,35,(3,8,40,23,31,1,33)	13,19,35,2,(1,26,38)	+	1,13,26,(13,28,12,5,7,11,31)
Builder convenience (32,34,36)	1,13,26,28,29,(11)	34,1,10,28,35	1,19,35,2,(12,20,11)	1,2,11	1,13,27,28	1,15,28,13,16,(7,11)	+

Seven different tables are created, such as Tables 5.1 and 5.2, and then the most repeated principles and the most inspirational principles are selected in Table 5.3. To recommend these principles in Table 5.3, their applicability at the project and example levels are considered. The first and second tables are summarized in the first and second lines of Archi-TRIZ, respectively. Our primary goal in creating Archi-TRIZ is to use it in the architectural design of the building to optimize the use of the interior non-structural components of the building. Despite this, the Archi-TRIZ matrix is not limited to this field. It may inspire creativity in other engineering fields in the construction industry. Table 5.4 presents forty inventive principles of

TRIZ, which summarize the concept of forty thousand inventions in sign language so that the designer can reach a creative solution by resolving two contradictions.

Table 5.4 Forty Inventive Principles of TRIZ
Taken from Coşkun and Altun (2011)

Inventive Principles 1 to 40					
1	Segmentation	14	Spheroidality-curvature	27	Cheap short living objects
2	Taking out	15	Dynamics	28	Mechanics substitution
3	Local quality	16	Partial or excessive actions	29	Pneumatics and hydraulics
4	Asymmetry	17	Another dimension	30	Flexible shells and thin films
5	Merging	18	Mechanical vibration	31	Porous materials
6	Universality	19	Periodic action	32	Colour changes
7	Nested doll	20	Continuity of useful action	33	Homogeneity
8	Anti-weight	21	Skipping	34	Discarding and recovering
9	Prior counteraction	22	Convert harm into benefit	35	Parameter changes
10	Preliminary action	23	Feedback	36	Phase transition
11	Beforehand cushioning	24	Intermediary	37	Thermal expansion
12	Equipotentiality	25	Self-service	38	Strong oxidants
13	The other way round	26	Copying	39	Inert atmosphere
				40	Composite materials

5.4.2 Validation of Matrix

5.4.2.1 Foldable Walls in the Building Plan

This section presents innovative designs utilizing the Archi-TRIZ and shows how it can be applied. It is possible to generate various architectural plans using foldable walls. The foldable wall is one of the innovative solutions through Archi-TRIZ that can address the diverse needs of different customers in an apartment. For example, tenants may have different preferences when a property owner wants to rent out an apartment. Innovative solutions to address such problems can be found by utilizing the Archi-TRIZ.

By moving two or three walls, a studio or one-bedroom apartment can be designed or converted to a two-bedroom apartment, which can have some challenges. If the location of the bathtub

and kitchen sink does not move, there would be fewer problems in project implementation. When the location of the bathroom and kitchen are changed, the pipes and ducts' location may need to be changed, which creates severe problems like:

- | | |
|------------------------------|---|
| 1. Pipeline | 7. Location of windows |
| 2. Electrical wiring | 8. Location of doors |
| 3. Hood place in the kitchen | 9. Location of wall cupboards |
| 4. Cabinets | 10. Location of radiators |
| 5. Bathtub | 11. Location of bathroom ventilation ducts |
| 6. Sink | 12. Duct location for water and sewage pipes in the kitchen |
| | 13. Location of the dishwasher |

Customers have the right to choose the plan for their apartment by designing movable walls that will not interrupt other factors mentioned in the last pages. They can select the place and size of the rooms. Also, the movement of walls cannot prevent the risk of wall collision with radiators. In the second scenario, the radiator can be exchanged with other options like heaters and air conditioners if the customer needs a vast degree of freedom for wall movement. Also, automated systems with sensors can be used to prevent wall movement when there is a possibility of collision between the wall and any other obstacles. In the other scenario, the wall movement can be limited during the apartment utility until it is vacant (without sensors).

5.4.2.2 Walls Properties Invention Based on Row 1 Column 2 of Archi-TRIZ

Whenever the wall's dimensions and physical characteristics want to be improved, then the speed and the time will be the worsening features. The solution can be derived from Archi-TRIZ principle number 29 (PN29), called preliminary anti-action or prior counteraction. When time and speed are worsening features, but dimensions and physical characteristics want to be improved, an Archi-TRIZ recommends the following principles:

- Principle number 29
- Principle number 10

- Principle number 8
- Principle number 15, etc.

Figure 5.2 illustrates Archi-TRIZ utilization to find innovative solutions.

PN29 (Pneumatics and hydraulics) recommends using parts with gas or liquid inside them rather than solid components (Genrich Altshuller et al., 2020). A pneumatic system could be used to construct a two-layer wall by getting inspiration via PN29. The wall thickness could be increased or decreased by installing a series of air jacks or airbags faster. Therefore, when 50 percent of the wall diameter moves inside the wall, the thickness of the wall will be reduced more quickly, and no time or speed will be lost in the process.

Principle number 10, “preliminary anti-action, prior counteraction,” refers to changing an object (either entirely or partially) before its changes are required. Organize the objects beforehand so they can be delivered to the most convenient location and used quickly. Prepare the objects beforehand to be able to place them into action at the most convenient location and without losing time in delivery (Genrich Altshuller et al., 2020).

Through the application of this principle, two-layer walls can be designed and constructed by companies with prefabricated parts. This will speed up the construction of movable walls in a home project and reduce the time required for installation. In addition, it is possible to design some keys. One of the walls can be moved by pressing the appropriate key, and the number of rooms on the building plan can be reduced or increased. Consequently, we can have two bedrooms anytime instead of a one-bedroom apartment. Preliminary action (preliminary anti-action, prior counteraction) can inspire designers to consider creating a manual or even automatic key with sensors to move the wall at a specific time and to a particular location in addition to prefabricated parts made in a factory for the two-layer walls.

Worsening Feature Improving Feature	Dimensions and physical characteristics of the BNSC (1,3,5,7,12)	Speed and time (9,25)	Strength and stability of BNSC (10,11,13,21)	Durability of the BNSC (14,27,29,30,31)	Energy (17,18,19,20,22)	Ease of use and user satisfaction (33,35,37,38)	Builder convenience (32,34,36)
Dimensions and physical characteristics of the BNSC (1,3,5,7,12)	+	29,10,8,15,20,38	10,35,1,(18,36,37,33,21,31)	40,1,35,(14,28,22,2,33,39,9,30,7,11,31)	15,19,32,2,(34,35,39,7,31,38)	15,26,29,(35,1,24,30)	1,28,13,26,(11)
Speed and time (9,25)	34,29,10,2,(13,4,5,35,20,7,38)	+	35,6,(5,10,19,28,36,37,38,20,33)	35,28,18,(3,24,26,11)	35,19,18,1,(5,20,38)	28,10,(18,32,34,35)	28,34,(1,4,10,35)
Strength and stability of BNSC (10,11,13,21)	10,35,15,36,(31,9,11,38)	35,36,15,(10,28,37,6,20,33)	+	35,27,18,2,(9,11,33)	2,10,14,16,19,35,(25,38)	35,2,17,19,(30,20,11)	35,10,1,(2,19,26,20,11)
Durability of the BNSC (14,27,29,30,31)	1,10,15,22,35,40,(8,4,9,7,23,30,11,33)	28,35,10,(3,18,21,22,26,32,11)	35,18,2,10,3,28,(30,11,31,33)	+	35,2,19,32,10,22,(24,21,11,33)	27,40,2,(3,15,32,35,25,23,11,31,33)	2,1,10,11,35,(25,31)
Energy (17,18,19,20,22)	19,18,32,15,(2,6,12,13,28,7,30,31)	35,18,19,(10,28,38,7)	19,2,32,35,21	35,2,19,22,3,1,2,1,33	+	35,2,19,(15,26,31)	28,2,16,17,26,7
Ease of use and user satisfaction (33,35,37,38)	1,13,15,17,35,(16,28,29,7)	28,35,10,(4,34)	35,30,2,(1,28,32,20,39)	28,32,2,27,35,(3,8,40,23,31,1,1,33)	13,19,35,2,(1,26,38)	+	1,13,26,(13,28,12,5,7,11,31)
Builder convenience (32,34,36)	1,13,26,28,29,(11)	34,1,10,28,35	1,19,35,2,(12,20,11)	1,2,11	1,13,27,28	1,15,28,13,16,(7,11)	+

Recommended Inventive principle numbers from ARCHI-TRIZ to solve the contradiction	Title of each recommended principle by Archi-TRIZ (based on Table 4)	Description of each principle	Our solution (OS) based on each principle
Principle 29	Pneumatics and hydraulics	It recommends using parts with gas or liquid inside rather than solid components.	1-design a two-layer wall with a pneumatic system inside it. 2- Air jacks or airbags can be installed to change the wall's diameter. 3- This system will reduce the wall's diameter faster , so speed and time will not be lost. Principle 10
Principle 10	Preliminary Action	In principle number ten, "preliminary anti-action, prior counteraction" refers to changing an object (either fully or partially) before its changes are required. Organize the objects beforehand so they can be delivered to the most convenient location and used quickly. Prepare the objects beforehand so they can be placed into action at the most convenient location without wasting time on delivery.	1- To reduce installation time, two-layer walls can be designed and constructed with prefabricated parts . 2- It is possible to design some keys. One of the walls can be moved by pressing the appropriate key, and the number of rooms on the building plan can be reduced or increased. 3-It can inspire designers to consider creating a manual or even automatic key with sensors to move the wall at a specific time and to a specific location.
Principle 8	Anti-weight	It suggests merging an object's weight with others that provide a lift. Therefore, an object's weight can be controlled by its environment (for example, using aerodynamic, hydrodynamic, and buoyancy forces).	This means that hydrodynamic or aerodynamic forces can compensate for the object's weight . In other words, a wall can be designed using hydrodynamic or aerodynamic forces and can go up and down in the Z direction (Figure 3). So, this solution can move the wall faster.
Principle 15	Dynamics	1- Dynamicity refers to the idea that an object's components should be changeable or dynamic . 2- So, these components can become optimal or recommend finding optimal operating conditions . 3-Furthermore, it recommends the division of an object into parts that can move relative to each other . 4- Additionally, this inventive principle recommends that a rigid or inflexible object (or process) be made movable or adaptable .	The wall specifications can be dynamic and adaptable to the conditions of the occupants. Also, the wall could be designed to be automatically adjusted for optimal operation at each movement step. Also, it is inspiring for a designer to develop a home that can have both a manual wall movement control system and an automated wall movement control system controlled by computer systems with sensors installed in each bedroom and hallway depending on whether the occupants are present during the day or at night in which area of the apartment. Therefore, the apartment can have a larger hall area during the day by moving walls to allow one bedroom to be eliminated by a manual or automatic time-setting system for optimal space utilization .

Figure 5.2 How to Use Archi-TRIZ

Principle number 8, “Anti-weight, Counterweight, Levitation,” describes compensating for an object’s weight, merging it with other objects that provide lift. As a result of applying this principle, an object’s weight can be controlled by interacting with its environment (for example, using aerodynamic, hydrodynamic, and buoyancy forces). It means that the object’s weight can be compensated with hydrodynamic or aerodynamic forces. A wall that can go up and down (Z direction) instead of moving in the X and Y direction can be designed by hydrodynamic or aerodynamic forces (Figure 5.5). The wall can be moved faster by this solution. Furthermore, if a wall is shifted in the Z direction to the roof, it will be hidden from view; for this reason, a unique space could be designed within the roof. The movement of the wall in the Z direction will also result in less floor space occupied.

PN15 (dynamicity) refers to the idea that an object’s components should be changeable or dynamic. These components can become optimal or recommend finding an optimal operating condition. Furthermore, it suggests dividing an object into parts that can move relative to each other. Additionally, this inventive principle recommends that a rigid or inflexible object (or process) be made movable or adaptable (Genrich Altshuller et al., 2020).

Using this inventive principle as inspiration, the designer can develop a solution like the following. It comes to mind that the wall specifications can have dynamicity and adaptability to the conditions of the occupants. This principle also inspires the designer to find the optimal operating system based on different situations. As a result, the wall could be designed to be automatically adjusted for optimal operation at each step of movement. Also, it is inspiring for a designer to develop a home that can have both a manual wall movement control system and an automated wall movement control system controlled by computer systems with sensors installed in each bedroom and hallway depending on whether the occupants are present during the day or at night in which area of the apartment. Therefore, the apartment can have a larger hall area during the day by moving walls to allow one bedroom to be eliminated by a manual or automatic time-setting system for optimal space utilization. As the walls and furniture in the apartment are movable, the apartment can have an additional bedroom during the night to allow privacy to the occupants. This wall can have an automatic system equipped with cameras and

sensors to consider the number of individuals in each apartment area and operate the wall movement without manual bottoms. This is just one of the possible solutions.

In the following picture, we have provided a detailed description of our first solution. Our solution based on PN15: Adjust the specifications of the wall to ensure that it is automatically adjusted for optimal operation at each step. It is possible for us to design and construct a two-layer wall that incorporates a pneumatic system. The home can have a manual electrical system for controlling the wall movement with just a few keys and an automatic electrical system controlled by computer systems, with sensors in each room and hall.

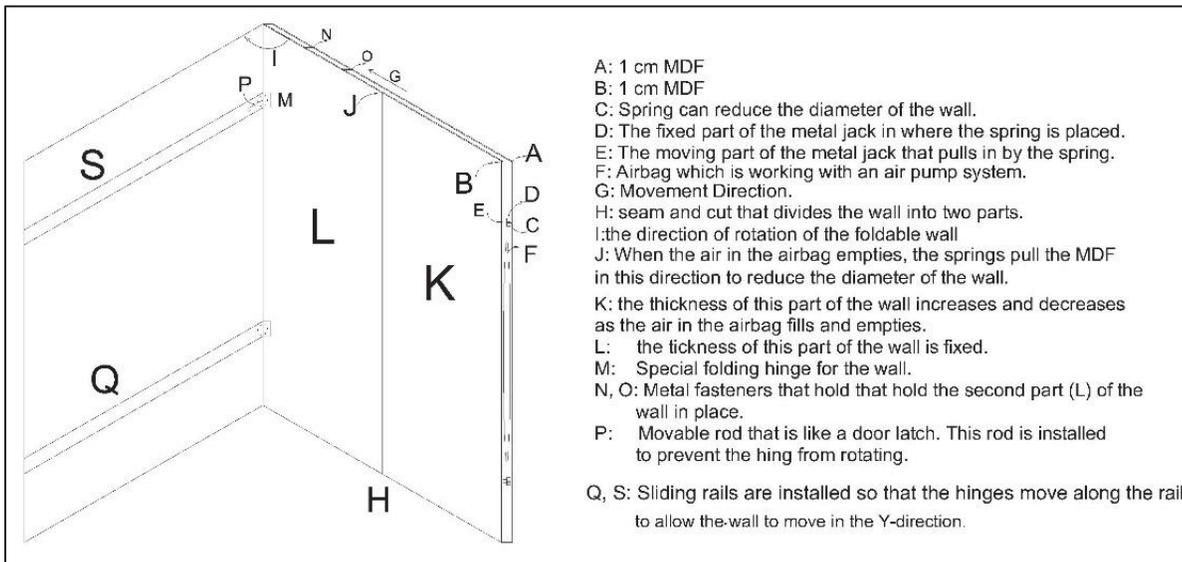


Figure 5.3 Foldable Wall Details

This system can be designed and built as illustrated in Figure 5.4

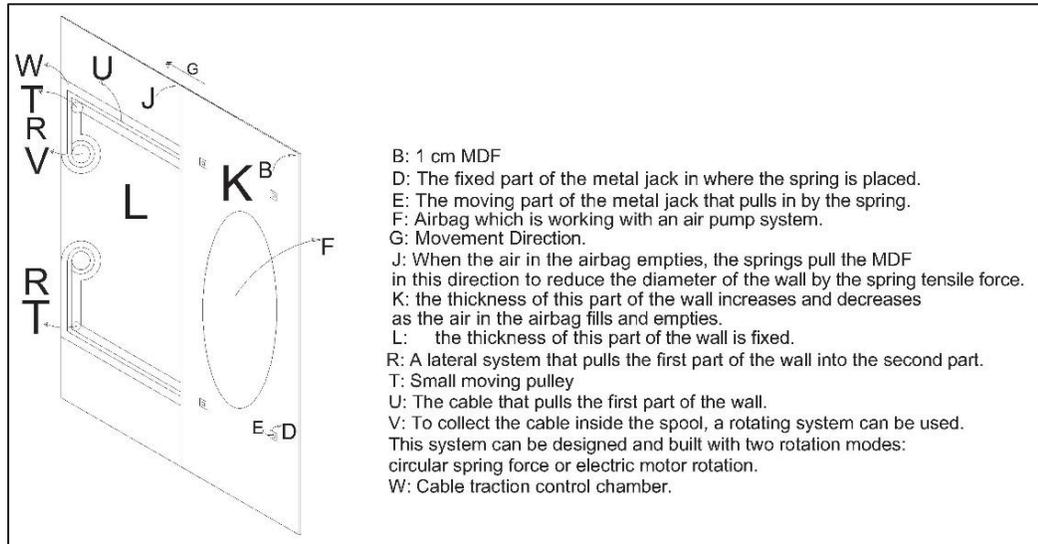


Figure 5.4 Foldable Wall Details

Figure 5.5 shows another solution for a foldable wall based on principle number 8. The direction of rotation of the wall can be changed, and the wall can be rotated to the ceiling using a hydraulic jack or any other manual or electrical system. This new method has more mobility and fewer obstacles to installing sliding rails, but its cost will be slightly higher than the previous method.

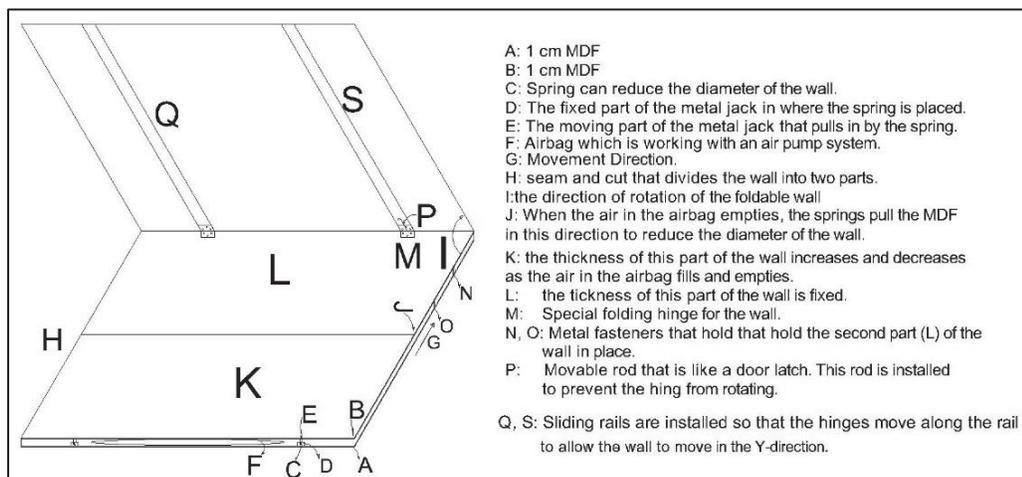


Figure 5.5 Solution for Foldable Wall

5.4.2.3 Utilizing the Invented Movable Wall System for Designing Different Plans

In this two-bedroom plan, two movable walls need to be designed to have a one-bedroom home or studio apartment based on the customer's preferences, like Figure 5.6. It means different plans can be generated by moving walls.

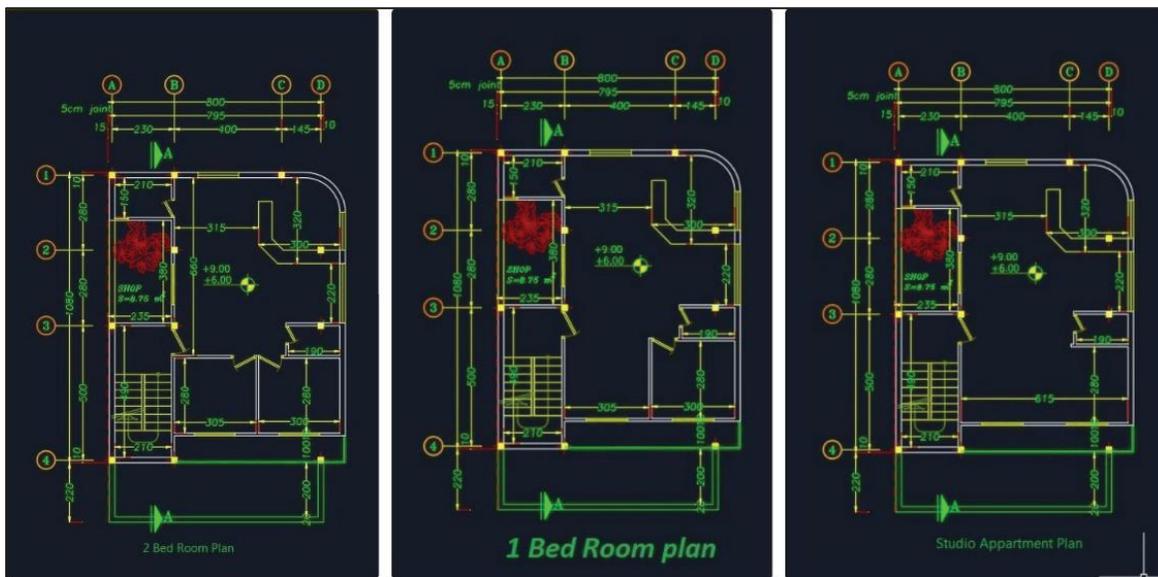


Figure 5.6 Studio, One- and Two-Bedroom Apartment Plans

Description of Section 7*7 Archi-TRIZ

Each principle in Archi-TRIZ can solve many contradictions alone; the last part of the matrix will be described as follows. The improving feature is “Builder convenience,” and the worsening feature is “Ease of use and user satisfaction.” In this case, an innovative solution needs to be generated to improve both improving and worsening features.

Principle Number 1 (PN1): Segmentation shows that the wall can be divided into smaller parts to accelerate the process of folding and opening the walls. In this case, increasing the builder's convenience will not worsen the ease of use. It is noteworthy that preparing, transporting, and installing smaller parts are easier for builders than bigger ones. On the other hand, having smaller parts for the wall will decrease the occupied space by the folded wall. This will

decrease the inconvenience of the user. In addition, the ease of use will increase. Consequently, user satisfaction will increase while the builder's convenience improves.

Principle Number 15 (PN15): Dynamicity and optimization show that the automatic system can be designed. When the person came out of the bedroom space, the walls moved automatically using the detector sensors, and the living room space became larger.

Principle Number 28 (PN28): Replacement of a mechanical system with "fields" shows that the electromagnetic system can be utilized. When the walls need to move, the electromagnetic system can perform better than the mechanical system.

Principle Number 13 (PN13): Inversion is the other way around; instead of moving the walls directly, you can use parts in the ceiling or side walls that move the main wall indirectly by moving the ceiling or side walls.

Principle Number 16 (PN16): Partial or excessive action. Some users need more space, so the wall can be moved a little more to prepare extra space and ensure there is enough for the occupants.

5.4.2.4 Testing 2*5 Section of the Matrix: (Row 2 and Column 5)

In this section, the applicability of Archi-TRIZ is verified. The 2*5 parts of the Matrix are examined. The improving feature is "Speed and time," and the worsening feature is "Energy." In this case, an innovative solution should be found to improve energy consumption (worsening feature) while improving speed and time.

For example, solutions number 35, 19, 18, 1, (5, 20, 38) have been recommended by Archi-TRIZ to solve this contradiction. Principle number 19 (PN19), Periodic Action, was inspirational for us. Instead of moving the wall in one step, a system can be designed to move the wall in a few steps to reduce high energy consumption. For this purpose, gears or pulleys can be used to increase power and reduce speed and distance. Move the walls using systems with high speed and distance but low force.

5.4.2.5 Archi-TRIZ Matrix Row 5 and Column 7 Testing

This part proves that this matrix is effective at inducing creative methods. A subproblem has been introduced to see how this matrix helps to strengthen and speed up creativity in the field of inventions in the field of internal building components. Suppose there is a small studio, and the occupants want to use its space optimally during the day. Therefore, it can be planned to fold the bed toward the wall to have more open space in the room during the day. Also, the bed can be moved to the ceiling to have suitable empty space under it so that the heavy bed can be lifted with less energy consumption. Here, the user energy and the builder's convenience need to be considered. As the "Energy" characteristic is an improving feature, as shown in Archi-TRIZ, "builder convenience" becomes a worsening feature. To resolve this contradiction, Archi-Matrix has introduced Solution numbers 28 (Mechanics substitution), 2 (Taking out), 16 (partial or excessive action), 17 (another dimension), and 26 (copying). First, Solution 28's potential outcomes should be considered as a test. It recommends that mechanical systems be replaced by functionally equivalent electromagnetic systems in this example. Thus, the inventive can use electromagnetic systems instead of mechanical energy to lift the bed.

Principle number 2 suggests separating the disturbing feature or part of the object from it. For instance, in this case, the electronic component or the electric motor that can be used to move this bed should be placed on the wall. It should be transferred movement to the bed with a belt or chain or electromagnetic power so that the weight of this electric component does not make the bed heavy and disturb its easy movement. Principle number 16 suggests the idea that if you can't make the bed up to the ceiling, you can have extra space in the room. Fold that bed against the wall to provide you with a lot of space during the day with less movement. Principle number 17 suggests moving into a new dimension—something like folded shutter doors. Therefore, with this suggestion, the bed can be designed in two or more smaller pieces. This is so that the two supports are folded first and then toward the wall. Principle number 26 recommends copying an initial sample. Therefore, you can make and display a small replica or picture of that bed from cardboard.

5.4.3 Mobile Application for Archi-TRIZ

A mobile application and website can be designed based on Archi-TRIZ and TRIZ. It is also possible to add ECA-TRIZ (Cherifi et al., 2019) or other special contradiction matrixes that can be derived from TRIZ for different fields of civil engineering in the future. In the first step, civil engineers or architects could choose their related and preferred matrix. Then, it is possible to choose worsening and improving features in this mobile application. In response, the mobile application will give the inventive solutions numbers and titles with descriptions. In this case, the innovators can solve contradictions by getting inspiration from these inventive principles to find innovative solutions. This mobile application has the possibility of adding additional information to it. In this regard, the mobile application could be improved gradually in the future. For instance, in the next article, we intend to add descriptions and some examples of inventive solutions for each of the forty inventive principles of TRIZ in architectural and civil engineering. Building designers will have more inventive examples, and they can inspire more quickly.

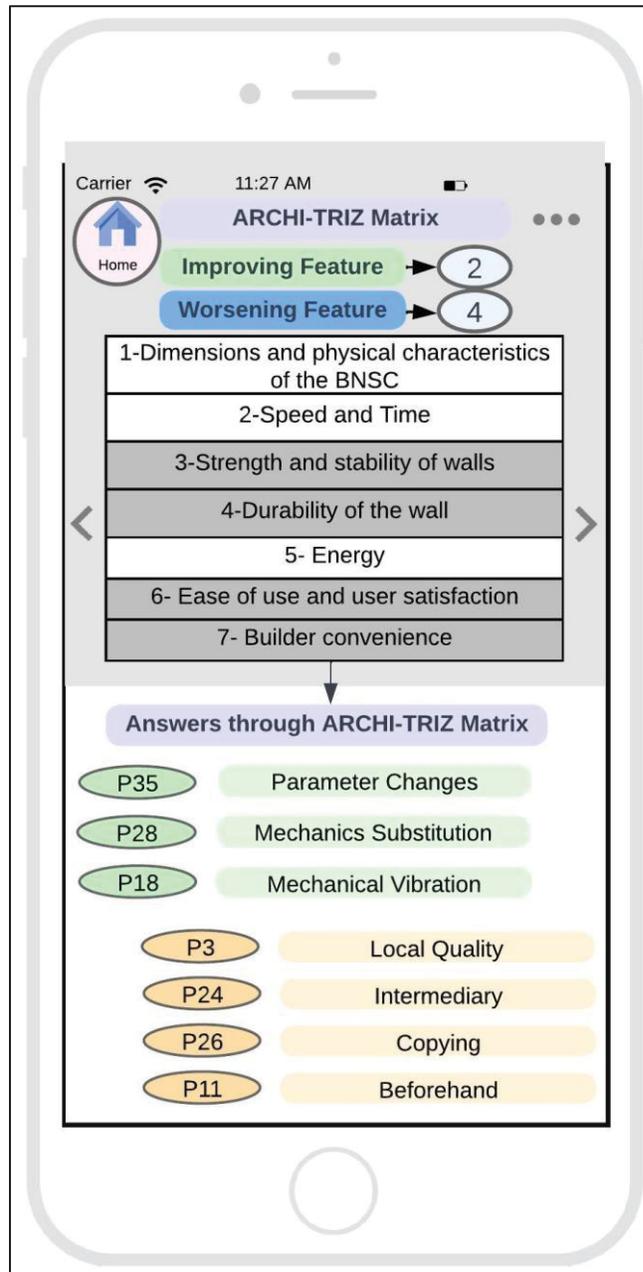


Figure 5.7 Mobile Application of Archi-TRIZ

5.5 Conclusions

Archi-TRIZ inspired us to design a changeable plan building for covering different customer's needs. It has been applied in a case study that resulted in an inventive solution. It should be

applied in other case studies. This methodology should accelerate the discovery of innovative solutions in the architectural and building industry and benefit this industry by inspiring designers to design more creative solutions.

5.6 Future Works

Many engineering fields are involved in project design and construction, such as civil engineering, structural engineering, soil and foundation engineering, environmental engineering, project management, architecture, earthquake engineering, etc. The Archi-TRIZ matrix is not limited to architecture and could be used in other fields as well. It may inspire creativity in other engineering fields in the construction industry. It is possible to produce other specialized matrixes for each civil engineering field in the future. These could be considered for future works.

5.7 AI Acknowledgment

The authors declare that generative AI or AI-assisted technologies were not used in any way to prepare, write, or complete essential authoring tasks in this manuscript.

5.8 Conflict of Interest

The authors declare that there is no conflict of interest.

CHAPTER 6

ARCHI-TRIZ PRINCIPLES' INVENTIVE EXAMPLES IN BUILDING DESIGN

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6.1 Abstract

TRIZ is an acronym for the Russian words "Theory of Inventive Problem-Solving." Altshuller reviewed 40,000 inventions and introduced 40 inventive principles. TRIZ has been used in many fields, however, TRIZ's direct utility in building design fields are difficult. This gap addressed by introducing a novel approach called the Archi-TRIZ Matrix in our previous research. Also, a mobile application designed by Archi-TRIZ, stating that by adding more features to this mobile application, innovation could be boosted in the building design industry. Furthermore, to boost brainstorming in building design process, additional examples of the 40 inventive principles applicable to architectural, civil engineering and, structural engineering projects are introduced. We have also added these examples as a new feature in our existing mobile application.

6.2 Introduction

TRIZ is an innovative problem-solving approach that is an acronym for "Theory of inventive problem-solving." A review of 40,000 Soviet Union inventions led Altshuller to introduce 40 inventive principles used by inventors indirectly in a TRIZ matrix. So, a TRIZ matrix contains improving and worsening features. When one feature has been enhanced, it negatively affects worsening features. By utilizing inventive principles that TRIZ has extracted, the inventor will prevent negatively affected worsening features. The use of recommended inventive principles

by TRIZ can be used to generate the best possible solutions. ("Genrikh Saulovich Altshuller's Biography.,"; Renev & Chechurin, 2016). There are several fields that use TRIZ in innovation, but only two percent of all TRIZ-related articles are related to the construction industry, according to SCOPUS. TRIZ has limited utility in the construction field, resulting in fewer inventions than in other industries. This limited number of articles focused on combining TRIZ with QFD or gave examples of TRIZ in a limited context (Oh et al., 2017). Despite this, none of the articles did not gathered enough examples in all fields of the construction industry fields, such as structural engineering, architectural design, earthquake engineering, and other construction fields, to give brainstorm with the civil engineers in the process of designing a building to boost inventions in the design process of building or construction projects as a guide, which is an important research gap in this study. Since most civil engineers are unfamiliar with TRIZ. This application will likely fill a significant gap in the construction industry. There is an article that introduces several examples of forty principles in the quality management field. These include quality assurance, customer needs and quality management, and other related fields. Different examples have been written under each principle, but none are in construction fields. Moreover, it has been mentioned that 40 inventive principles are applicable not only in engineering fields like architectural design of buildings but also in non-technical fields, including biology, marketing, etc (Retseptor, 2003). In another article, the summary of 40 principles has been summarized in a table, which can be used by software engineers as a tool to accelerate their innovation by brainstorming (Fulbright, 2004). Another article discusses the application of 40 principles with examples in the construction industry. However, most of the examples are in soil mechanics. The absence of explanations and examples in building design fields such as architecture, structural engineering, earthquake engineering, and others in this article persuades us to conduct our research to fill these gaps (Teplitskiy & Kourmev, 2005). This article outlines forty principles with examples from the food industry for accelerating innovation. This article aims to illustrate how collecting examples and relating them to 40 TRIZ principles within a field like the food industry can improve innovation among experts in that field (Mann & Winkless, 2001). Another article analyzes 176 construction patents in Taiwan and classifies them into seven categories. In addition, it shows that 53 of the 176 patents are from subclass E04G009/08, which is about

foldable or collapsible elements in the construction industry. In fact, one of the most inventive solutions that comes to the mind of civil engineers is using foldable elements in the construction industry. 86 patents out of 176 patents used inventive principle number 10 (preliminary action) of TRIZ, so this is the first-ranked principle among all 40 principles of the TRIZ. This important paper illustrates that many of the TRIZ principles used in the construction industry in Taiwan are not as useful as they could be. In other words, just 13 principles out of 40 had more than ten patents, and almost 30 of the TRIZ principles had less than ten patents in the construction industry (S. Cheng, Yu, Wu, & Chiu, 2006). It has been observed that other inventive principles could be utilized more than they were. In this study, several examples will explain these principles in detail to increase the possibility of using inventive principle number 1 to 40 in the construction industry.

In another research, TRIZ was used by authors to explain innovation in the construction industry using only three principles and three examples. These limited examples covered only some TRIZ principles regarding brainstorming for building designers (Mann & Catháin, 2005). There are two other papers in which the authors present some examples of forty principles of architecture, but they need to address all the subfields of the construction industry, such as structural engineering, civil engineering, earthquake engineering, etc. Additionally, Igor Labuda indicated that more research is necessary to fully equip designers with examples of how to accelerate innovation in the building industry (Labuda, 2015; Mann & Catháin, 2001). This study aims to fill this research gap by providing more inventive solutions in various fields of civil engineering, architectural design of buildings, and structural engineering so that building designers can brainstorm. Archi-TRIZ was designed in our previous research as a customized matrix for design building (Hassanijajini et al., 2024). A mobile application is designed to display the inventive principle numbers that Archi-TRIZ has recommended. We aim to gather these examples and descriptions of innovative solutions to that mobile application so that engineers will be inspired to achieve a higher level of innovation and novelty to fill this gap.

6.3 Methodology

Table 6.1 presents forty inventive principles of TRIZ, which summarize the concept of forty thousand inventions in sign language so that the designer can reach a creative solution by resolving two contradictions. In the following section, each principle in the building industry is described in more detail. Also, how each principle generates creative ideas for building design and construction projects has been explained. Our next step is creating some tables for architectures that provide easy access to information and maximize their creativity. The mobile application prototype is also designed for easy access to these examples so that this mobile application can serve as a tool to accelerate creativity in building design.

Table 6.1 Inventive Principle 1 to 40 of TRIZ
Taken from Coşkun and Altun (2011)

Inventive Principles 1 to 40				27	Cheap short living objects
1	Segmentation	14	Spheroidality-curvature	28	Mechanics substitution
2	Taking out	15	Dynamics	29	Pneumatics and hydraulics
3	Local quality	16	Partial or excessive actions	30	Flexible shells and thin films
4	Asymmetry	17	Another dimension	31	Porous materials
5	Merging	18	Mechanical vibration	32	Colour changes
6	Universality	19	Periodic action	33	Homogeneity
7	Nested doll	20	Continuity of useful action	34	Discarding and recovering
8	Anti-weight	21	Skipping	35	Parameter changes
9	Prior counteraction	22	Convert harm into benefit	36	Phase transition
10	Preliminary action	23	Feedback	37	Thermal expansion
11	Beforehand cushioning	24	Intermediary	38	Strong oxidants
12	Equipotentiality	25	Self-service	39	Inert atmosphere
13	The other way round	26	Copying	40	Composite materials

6.4 Results and Discussion

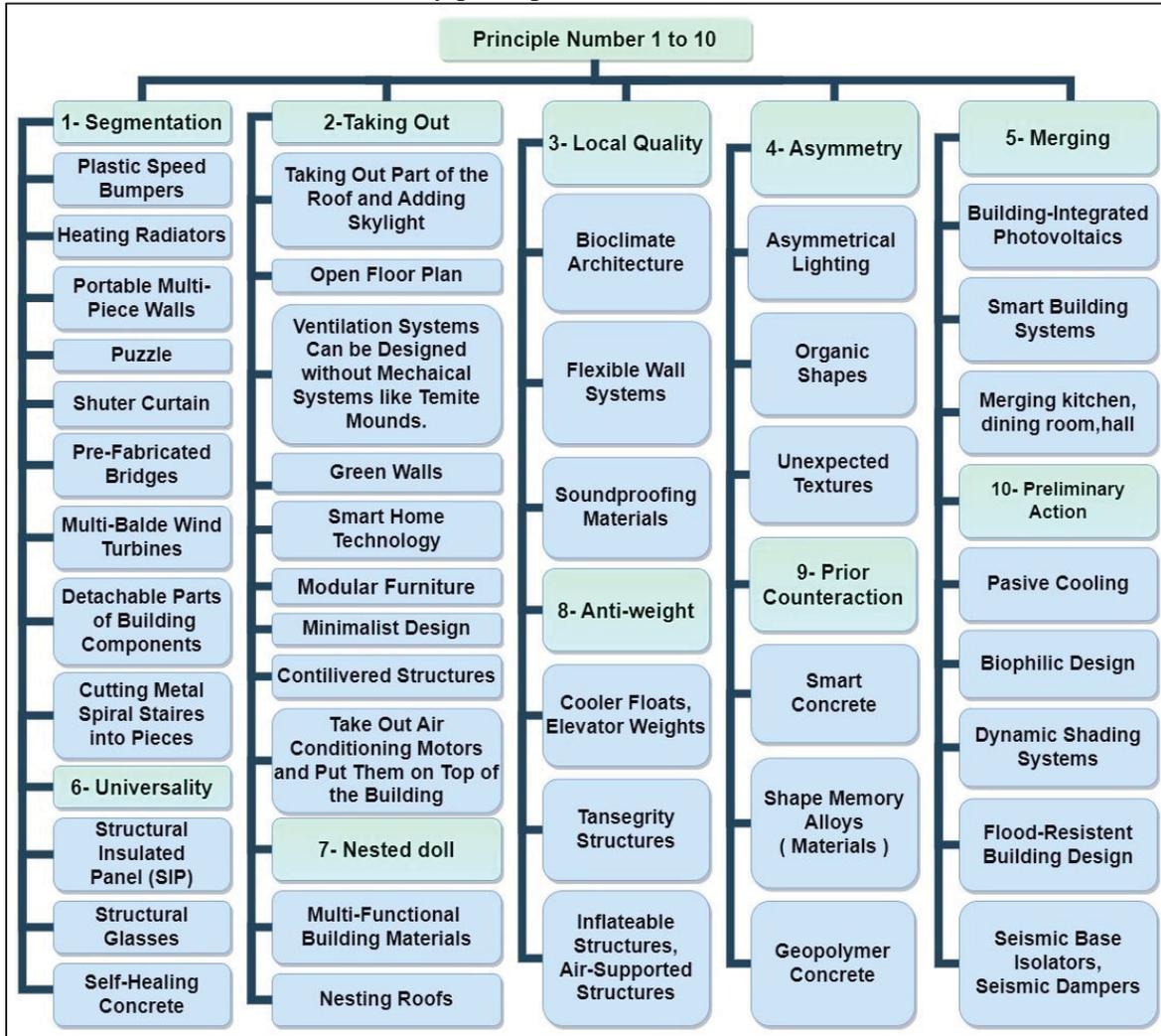
6.4.1 Segmentation

Segmentation encourages designers to separate the main object into its components or the degree of segmentation could be increased (Genrich Altshuller et al., 2020; Retseptor, 2003). examples of this principle are:

- A shutter curtains
- Plastic speed bumpers
- Heating radiators
- Metal structure, such as a prefabricated factory shed. This structure is prepared as separate metal pieces and assembled on-site with bolts and nuts. Prefabricated structures are used to improve the quality of structures and reduce their weight to improve their performance during earthquakes. Further, they are detachable and can be installed quickly. Consequently, they are able to save time and increase the quality of the structures (Paudel, Dulal, Bhandari, & Tomar, 2016).
- Prefabricated bridges consist of several parts, like beams and metal parts that are bolted or riveted together. This principle helps designers to reach this idea of making the pieces of the bridge smaller and lighter in size, like a puzzle, for easier transportation. As a result, it becomes easier to reach hard-to-access areas and speed up project implementation. So, the segmentation principle could reduce the costs and time of project (Hällmark, White, & Collin, 2012).

Table 6.2 shows additional examples of segmentation in construction industry.

Table 6.2 Possible creative solutions in the construction industry by principle number 1 to 10



6.4.2 Taking Out

Taking out can be described as extraction, which involves removing the annoying feature from a system or building and selecting only the required feature (Genrich Altshuller et al., 2020). Some creative examples are listed in table 6.2 and explained in the following:

- Moving the air conditioning motors to the top of the building to allow bathroom ventilation without causing unwanted noises.
- Birds flying around airports are hazardous if they accidentally crash into an airplane engine. Birds can be frightened by playing back the sound of their predator, which was

recorded on a tape and played back. So, taking out the birds at airports can increase airline safety.

- The blades of the large ventilator are designed to decrease the noise produced by its motor. A mechanical power transmission system is designed to move the fan in the shed window using belts and pulleys, but the motor is installed outside the building so that the loud noise will not disturb workers.
- A building ventilation system can be designed without mechanical systems by utilizing the natural ventilation system in termite mounds.
- The design of a bridge that can flex and absorb shock during earthquakes using the principle of tensile structures found in spider webs.
- Taking out a section of the roof and installing a skylight can create a well-light and energy-efficient room by reducing the need for artificial lighting.
- The concept of minimalist design is taking out unnecessary elements to achieve minimalist look. Simplicity, clarity, and order are achieved by removing excess elements. A good example is removing walls and partitions, which leads to creating open floor plans. For instance, modular furniture and interchangeable pieces can be easily reconfigured to fit different spaces.
- Combining multiple devices into one interconnected system eliminates various devices. By removing unnecessary components, smart home technology becomes more user-friendly.
- Vertical gardens created with plants known as green walls or living walls. The "taking out" principle allows a more compact and space-efficient design by eliminating separate planters or pots.

6.4.3 Local Quality

Local quality means improving effectiveness or quality of the part of the system or component (Genrich Altshuller et al., 2020).

- Bioclimatic architecture means maximizing natural resources while energy consumption is minimized. Comfortable and sustainable buildings can be created

using, natural ventilation, and other methods based on local environmental conditions (Toroxel & Silva, 2024).

- Creating temporary partitions and dividers in a larger space is easy with flexible wall systems. Typically, these systems are lightweight and can be reconfigured easily. "Local Quality" is embodied by flexible wall systems, which allow you to adapt a space to your needs.
- Noise transmission between rooms and buildings is reduced by soundproofing materials. Walls, floors, and ceilings can be covered with these materials. The "Local Quality" principle is inspirational because it encourages designers to focus on the local needs rather than taking a one-size-fits-all approach. For example, soundproofing materials can be used only in specific areas of the building instead of in all parts of the building.

6.4.4 Asymmetry

The principle of "Asymmetry" inspires designers to think outside the box and not use symmetry and balance in their design (Genrich Altshuller et al., 2020). Designers can create visually interesting, memorable, and engaging spaces by intentionally incorporating unexpected and asymmetrical elements.

- Asymmetrical lighting adds drama and depth to a space. This is done by spotlighting art pieces or placing pendant lights at different heights. Drawing attention to specific areas or objects within a room can be achieved with asymmetrical design.
- A space can look more attractive by adding organic shapes, such as curved walls and irregularly shaped furniture. Designers can create a sense of dynamism and movement by incorporating.
- Adding unexpected textures to a space, such as rough stone or smooth metal, can add visual interest. It is possible to create an engaging and memorable space by combining different textures asymmetrically.

6.4.5 Merging

Merging encourages designers to create solutions with combining technologies, or systems (Genrich Altshuller et al., 2020).

- Building-integrated photovoltaics (BIPV) combines the aspects of energy efficiency and architectural design by integrating solar panels into the building envelope, such as walls or roofs. It can replace traditional walls and produce green renewable energy (Heinstein, Ballif, & Perret-Aebi, 2013).
- Smart building systems merge and optimize building operations using sensors and controls, such as lighting, heating, ventilation, and air conditioning. As a result, they improve occupant comfort and energy efficiency.
- Merging spaces increase the area of the tiny spaces for example rather than a separate kitchen, it proposes an L-shaped kitchen that integrates the hall, dining room, and kitchen.

6.4.6 Universality

Inventors consider how their solution might apply beyond the specific problem and can be repurposed across various contexts. Designers can enhance products' versatility, efficiency, and effectiveness by focusing on universal properties and principles (Genrich Altshuller et al., 2020).

- The structural insulated panel (SIP), which is made of rigid foam insulation sandwiched between two structural boards. Walls, roofs, and floors can be built with them; they are excellent insulators (Panjehpour, Abang Ali, & Voo, 2013).
- Structural glass can be utilized as a building's load-bearing structure element. Structural glasses can be used instead of structural elements in special buildings like the cottages in the parks to create a transparent environment to watch animals.
- Self-healing concrete can repair cracks and other damage on its own. In this product, cracks can be filled by and prevent further damage. Self-healing concrete is universal

because it can be used anywhere, from earthquake-prone areas to high freeze-thaw cycles areas (De Belie et al., 2018).

6.4.7 Nested Dolls

Creating flexible, adaptable, and efficient solutions requires breaking complex systems into smaller, interconnected components. Nested dolls can lead to more sustainable solutions by making systems easy to maintain and upgrade over time, reducing the need for replacements or disposals (Genrich Altshuller et al., 2020).

- Multi-functional building materials can serve several functions, including insulation, structural support, and aesthetic appeal. Multiple layers can be assembled and stacked like nesting dolls. These layers are customizable and combine to create materials that can meet various building needs.
- Nesting roofs are designed to be nestled within one another, each layer providing additional insulation and protection. This approach can result in significant cost savings and improved durability over traditional roofing systems (Valluzzi et al., 2021).

6.4.8 Anti-Weight

The weight of an object can be compensated by lifting it with other object or forces. It can maximize energy efficiency (Genrich Altshuller et al., 2020).

- Aerodynamic or hydrodynamic forces are two ways an inventor can compensate for the weight of an object. There are several examples in construction engineering where this principle has been applied to invent creative solutions, such as cooler floats and elevator weights.
- Tensegrity structures are constructed by combining tension and compression to provide lightweight, self-supporting structures that can be used for everything from bridges to buildings (Skelton, Helton, Adhikari, Pinaud, & Chan, 2017).
- Air-supported structures can be used to construct temporary or semi-permanent buildings. A lightweight, modular structure can be created using inflatable structures

that can be erected and dismantled quickly, making them ideal for temporary structures such as event venues and disaster relief shelters (Lutes, 1971).

6.4.9 Prior Counteraction

Prior counteraction can inspire engineers to anticipate and address significant potential problems (Genrich Altshuller et al., 2020).

- Smart concrete is capable of sensing and responding to changes in its environment, such as changes in temperature and pressure. Sensors embedded in the concrete monitor its condition and alert the user when damage or deformation occurs, which allows for early intervention and maintenance before major structural failure occurs. The sensor technology allows for early intervention before the problem worsens (B. Han et al., 2015).
- Shape Memory Alloys are materials that can change shape when their temperature changes. In the construction of buildings and bridges, these alloys are being used to create structures that can withstand changing weather conditions, including wind, snow, and earthquakes. As these structures are designed to move and flex in response to external forces, prior counteraction is applied to prevent damage and failure (Janke, Czaderski, Motavalli, & Ruth, 2005; Naresh, Bose, & Rao, 2016).
- Geopolymer concrete made from industrial waste materials, including fly ash and slag. This concrete has lower carbon emission and more excellent durability compared to traditional concrete (Mohajerani et al., 2019).

6.4.10 Preliminary Action

This principle inspires designers to take proactive steps to resolve potential problems before they arise. Thus, these solutions can often be more effective than reactive solutions that address problems after they have already occurred (Genrich Altshuller et al., 2020).

- Passive cooling relies on natural ventilation, shading, and insulation to maintain a comfortable temperature in a building without using electricity. Accordingly, this

principle is applied by using a system that reduces the need for energy-intensive air conditioning systems (Oropeza-Perez & Østergaard, 2018).

- Biophilic Design incorporates natural elements in building design to enhance human health and well-being. The natural elements can include indoor greenery, natural lighting, and natural materials (Gillis & Gatersleben, 2015).
- Dynamic shading systems use sensors and automation to regulate how much sunlight enters a building based on weather conditions and occupancy levels. They can reduce energy consumption, improve thermal comfort, and increase occupant productivity. Preliminary action is being applied here through proactively optimizing building systems before energy is wasted (Al-Masrani & Al-Obaidi, 2019).
- Flood-resistant building designs employ elevated structures, waterproof materials, and other strategies to reduce the impact of floods on buildings (Proverbs & Lamond, 2017).
- The construction of earthquake-resistant buildings is another example of this principle. Some essential buildings, such as hospitals, are equipped with seismic base isolators or seismic dampers that absorb seismic waves' energy to avoid possible earthquake damage (Kumar, 2020).

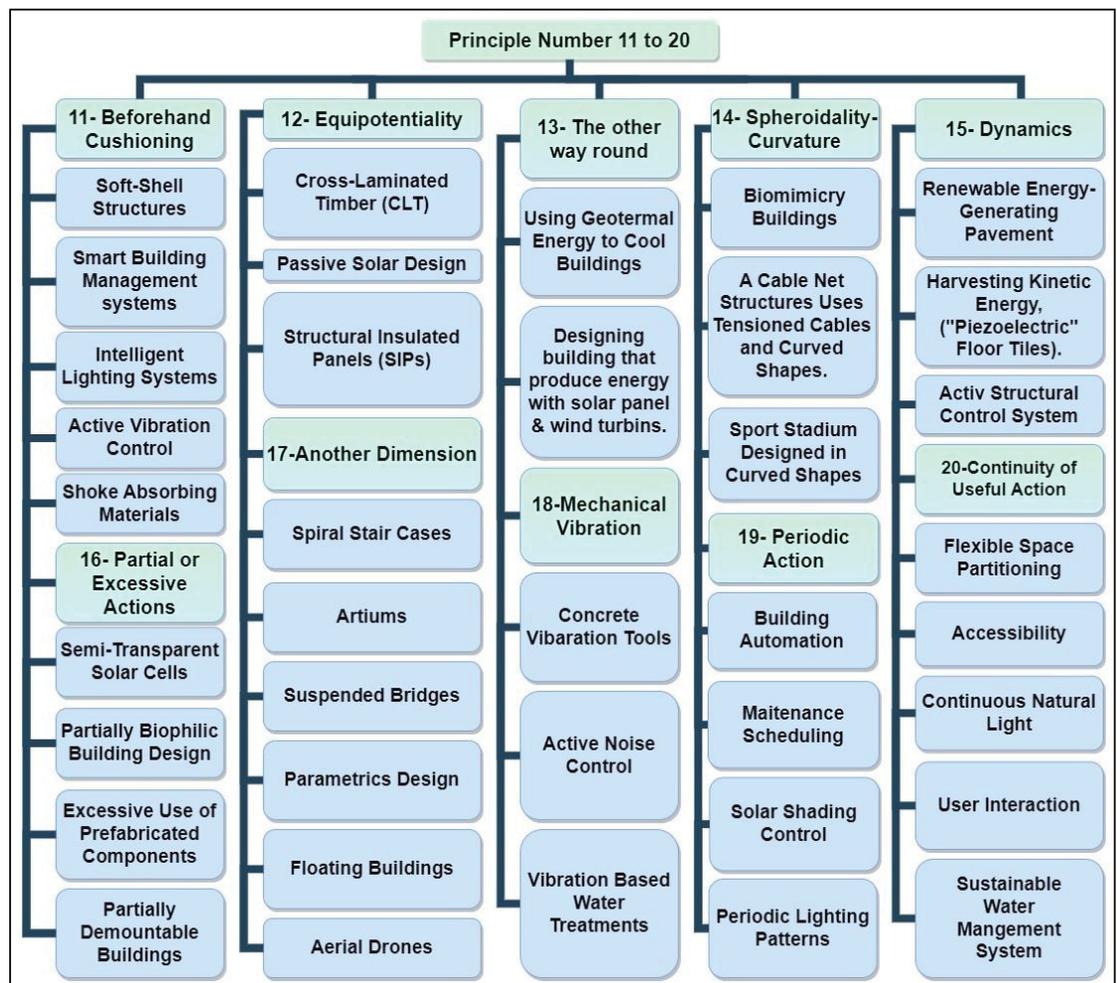
6.4.11 Beforehand Cushioning

Engineers are inspired by the principle of cushioning beforehand since it motivates them to take proactive measures to predict and mitigate potential problems before their occurrence (Genrich Altshuller et al., 2020).

- Soft-Shell Structures use flexible materials, such as fabric or polymer, to create a cushioning effect that absorbs impact and distributes loads.
- Smart Building Management Systems use sensors and automation to optimize building systems, including lighting, HVAC, and security. As a result of these systems, potential problems can be identified and corrected before they become significant problems.

- Intelligent lighting systems uses sensors and automation to adjust lighting levels according to occupancy, time of day, and natural lighting conditions (Koval, Martsenko, & Zin, 2023).
- Active Vibration Control uses sensors and actuators to actively control vibrations in buildings to prevent structural damage to the building (Ramírez-Neria, Morales-Valdez, & Yu, 2022).
- This principle can also be observed in using shock-absorbing materials, such as foam, rubber, and airbags, which can be incorporated into the structure of various building components, such as floors, walls, and roofs, to provide cushioning and absorb impact.

Table 6.3 Possible creative solutions in the construction industry by principle number 11 to 20



6.4.12 Equipotentiality

The principle of equipotentiality encourages engineers to ensure that all system parts are equal and balanced (Genrich Altshuller et al., 2020).

- The cross-laminated timber (CLT) is an engineered wood product made by gluing layers of lumber together in alternating directions. CLT can replace concrete and steel in some building applications due to its strength, durability, and versatility. Using this approach maximizes the use of renewable resources (wood) and ensures that all parts of the building are equal in strength, according to the equipotentiality principle (Kurzinski, Crovella, & Kremer, 2022).
- The passive solar design of a building maximizes natural light and heat to reduce energy consumption. In passive solar design, a building is oriented to maximize solar exposure, and materials that retain and distribute heat effectively are selected, ensuring that all parts of the building receive an equal amount of natural light and warmth (Qiu, Wang, Yu, Liao, & Li, 2021).
- Structural insulated panels (SIPs) are prefabricated building materials with an insulating foam layer sandwiched between two structural faces. The use of SIPs maximizes the use of the entire building envelope since they provide excellent insulation and can be used for walls, floors, and roofs (Amran et al., 2020).

6.4.13 The Other Way Round

This principle inspires designers to consider inverted actions to solve problems, such as moving the fixed part in the system or fixing the moveable part in that system (Genrich Altshuller et al., 2020).

Inventors have applied this principle to the building industry to develop sustainable, functional, and aesthetically pleasing solutions. Traditionally, buildings are cooled by air conditioning, which consumes a great deal of energy and is expensive. Instead, engineers use

geothermal energy to cool buildings by taking advantage of the earth's stable temperature a few feet underground, reducing energy consumption and improving environmental performance. The traditional approach to designing buildings focuses on making them as energy-efficient as possible. In contrast, engineers designed buildings that produce energy using technologies such as solar panels, wind turbines, and geothermal systems based on the "The other way round" principle (Breesch, Bossaer, & Janssens, 2005; Maerefat & Haghghi, 2010; Oropeza-Perez & Østergaard, 2018).

6.4.14 Spheroidality-Curvature

It encourages designer to think creatively about using curved shapes and angles to create innovative solutions to complex problems (Genrich Altshuller et al., 2020). The principle of spheroidal -curvature is used to inspire building design with Biomimicry Buildings, in which architects and engineers mimic the shapes and structures found in nature. Termites' mound has a very efficient natural ventilation system. Building designers can inspire termites' mound spheroidal structure to design walls that have the membrane with breath ability instead of barriers. Designers can learn from the nature shapes and structures like termites to improve their design (Chayaamor-Heil & Hannachi-Belkadi, 2017).

A building's efficiency, sustainability, and resilience can be improved by studying the curves and shapes found in natural systems. For instance, designers can be inspired by the curved structural system that is naturally woven by spiders to design a structural system that has sensors to send the signals to the central system in case of any vibration to do active control of structures by several appropriate tools (Nasr, 2017).

6.4.15 Dynamics

Dynamic principle is indicating to designers that if an object is static divide it to moveable parts. It is also recommending if a process or object is inflexible, make it movable or dynamic or flexible (Genrich Altshuller et al., 2020).

The following examples illustrate how the Dynamics principle can be applied in various ways to develop more efficient solutions in the construction industry.

Scientists have developed a pavement type that generates electricity through vehicle movement. The pavement comprises a series of interconnected modules that generate electricity when compressed by the weight of passing vehicles. Engineering professionals are developing new systems for harvesting kinetic energy from the movement of people within a building. People can generate electricity by walking over "piezoelectric" floor tiles. This solution can be connected to the principle of "Dynamics" by creating a system that can dynamically respond to people's movements.

Active structural control systems can adjust to changes in dynamic loads such as waves, winds, and earthquakes, providing structures that are more robust and efficient (Korkmaz, 2011; Soong & Spencer Jr Reviewer, 1992).

6.4.16 Partial or Excessive Actions

This principle is indicating that If achieving a goal completely is hard. Then it may be easier to solve the problem by the same method by doing that method slightly more or less than its normal utility could solve the issue (Genrich Altshuller et al., 2020). Consideration of partial or excessive actions can challenge traditional assumptions and push the limits of what is possible. There are some examples in the following:

- As an alternative to conventional opaque solar panels, engineers can create semi-transparent solar cells that allow some light to pass through. By using this technology, not only energy can be generated, but also natural light can be provided in a building (Sun & Jasieniak, 2017).
- Engineers can design partially biophilic buildings that promote well-being and mental health by incorporating elements of nature into their designs. Lighting from natural sources, green roofs, and indoor plants can assist in achieving this objective. Natural shapes and curves can also be used in the interior design of the building to avoid repetition and make the space more appealing (Gillis & Gatersleben, 2015).

- Excessive use of prefabricated components can reduce construction waste and costs while ensuring consistency in the quality of the building. Prefabricated components can be manufactured precisely to meet the project's specifications, which could minimize waste but it may take more time because of planning and managing all parts of the project in a perfect way (Tam & Hao, 2014).
- Demountable Precast Concrete Frame–Building System for Seismic Regions have been produced in the USA. these kinds of buildings are environmentally friendly because they can be detachable and reusable. If the fully demountable building is difficult to design and construct due to technical issues, then it can be designed as partially demountable. For instance, in New Zealand, a partially demountable concrete carpark building has been designed and constructed which is also seismically safe. (Aninthaneni & Dhakal, 2017).

6.4.17 Another Dimension

This principle is recommending moving an object in another dimension in 2 D or 3-dimensional space to solve the problem creatively. In other words, if you have an object then use its other side to solve the problem. Additionally, use multistory arrangement instead on single story arrangement to solve the problem creatively (Genrich Altshuller et al., 2020). The engineers can create innovative structures that meet the occupants' needs by considering the building's relationship with its environment and exploring unconventional building forms. Some examples of using another dimension principle in construction are listed below:

- An architect can design spiral staircases that curve around a central axis, providing an elegant and space-saving solution for circulating vertically within a building by inspiring from moving to a new dimension. Adding this solution to the building's design creates a striking visual feature that can also improve the functionality of the building (Hassanijajini & Gardoni, 2022)
- Architectural atriums can be designed vertically through a building, providing a central gathering space and increasing natural light and ventilation (Holford & Hunt, 2003).

- The design of suspended bridges can provide pedestrian pathways between two or more buildings, adding further dimension to the building's interaction with the surrounding environment.
- Architects can utilize parametric design tools to create complex and dynamic building forms that can be tailored to specific site conditions, such as solar orientation and wind patterns like the rotating Sharifiha house (Schumacher, Vogt, & Krumme, 2019).
- Engineers can design structures for oil with buoyant foundations by getting inspiration of another dimension instead of going down to the underground, they can construct foundation on the ground that are stable on soft clay soil (Pike & Saurin, 1952).
- Using the inventive principle of "Another Dimension," engineers can think about utilizing aerial drones that is controlled by computer vision using machine learning to inspect any damages in building including cracks instead of human workers, a safer and more efficient alternative (Munawar, Ullah, Heravi, Thaheem, & Maqsoom, 2021).

6.4.18 Mechanical Vibrations

Mechanical vibration means oscillation or vibration within an object's structure. These kinds of vibration can be made by increasing its frequency even up to ultrasonic or piezoelectric vibrators. The other approaches for vibration is including electromagnetic or even ultrasonic field oscillations or combination of both of them (Genrich Altshuller et al., 2020).

- Structures such as bridges and residential buildings require dense concrete without air bubbles to achieve maximum strength. Vibration tools are recommended to remove unwanted air bubbles from the concrete, preventing weaknesses in vacant points and producing more compacted concrete (Tattersall & Baker, 1988).
- One of the most important environmental problem of construction industry is noise pollution. So, the construction equipment noise can be reduced by using active noise control techniques in construction phase of the building (Kwon, Park, Lee, Ahn, & Shin, 2016).
- Water treatment can involve various methods, but many of these methods can be energy-intensive and costly. Engineers are currently investigating using vibration-

based methods, such as ultrasonic waves, to remove impurities from water to break up contaminants (Doosti, Kargar, & Sayadi, 2012; Fetyan & Salem Attia, 2020).

6.4.19 Periodic Action Principle

This principle is stating that instead of continuous action, make some pauses between impulses to convert continuous action to periodic action or if the action is periodic, change the frequency or magnitude of that periodic action to lead your purpose perfectly (Genrich Altshuller et al., 2020).

- Automating building systems by taking periodic actions, such as turning lights on and off at specified times or adjusting heating and cooling systems based on occupancy patterns is possible.
- Periodic maintenance schedules can be developed for building systems and equipment to prevent failures and extend their lifespan. Periodic actions can be taken to monitor structural health. Monitoring the structural vibrations of a building periodically may be useful in detecting and responding to potential structural defects.
- Using periodic actions in "solar shading control" louvers and blinds may be adjusted periodically throughout the day to maximize the amount of solar heat gained and daylight penetration inside a building.
- Designers of building facades may also benefit from periodic action in lighting design. A repeating light sequence can be used to create a visually engaging building facade by using periodic lighting patterns.

6.4.20 Continuity of Useful Action

This principle is indicating that do the action continuously and use all the parts fully loaded to achieve the goal. Moreover, eliminate all time consuming and unnecessary actions or works that could be distractors (Genrich Altshuller et al., 2020).

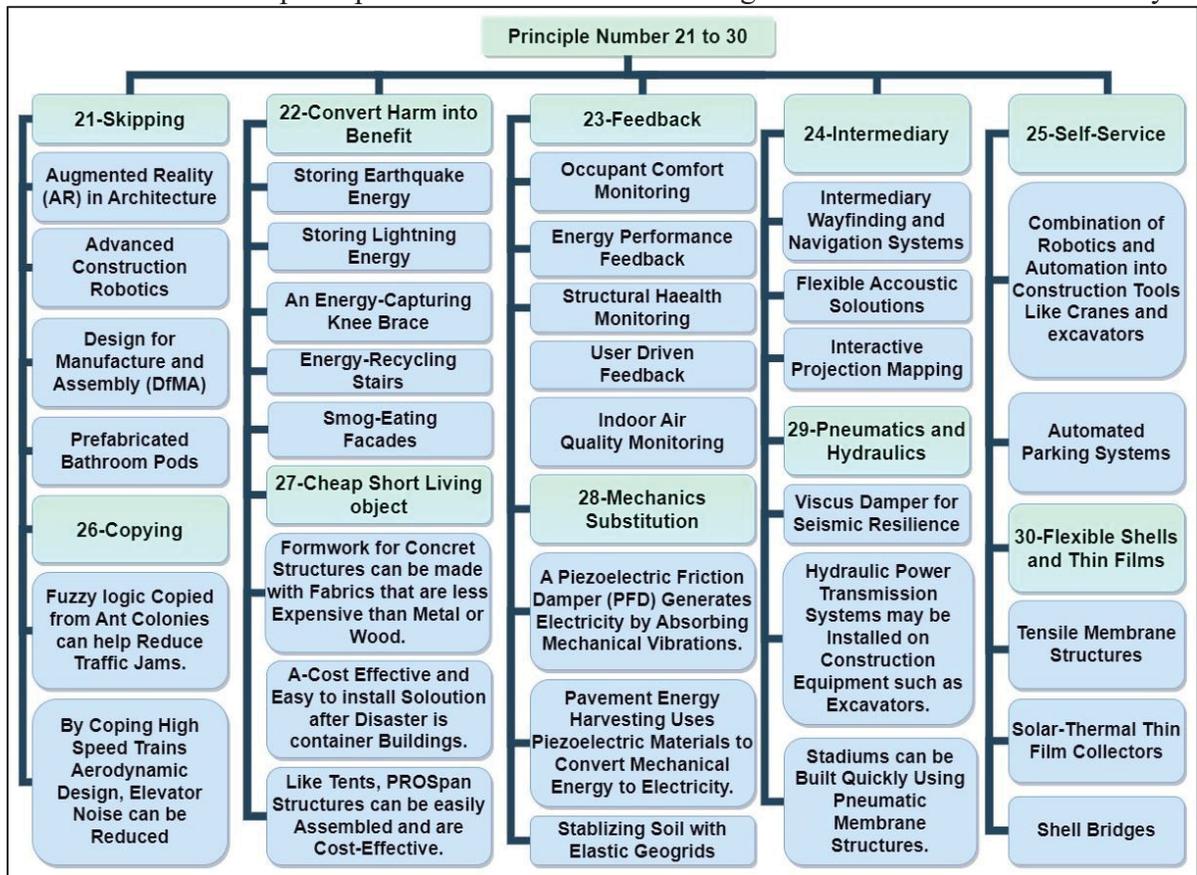
- A flexible space partitioning system can be continuously adjusted to meet occupants' needs.

- In the case of emergency patients who will be transported to the hospital with a stretcher, the building should be continuously accessible to all types of users. Various solutions are available, such as ramps and elevators, which are appropriate for ambulances and elderly individuals for continuous access.
- For example, buildings can be designed with a constant supply of daylight. Large windows and mirrors in a rotatable system can provide constant light intensity during the day by reflecting the light through adjustable mirrors to the roof of the building during periods of low sunlight. Additionally, a small wind turbine can be installed adjacent to the window to store wind energy in a battery in the form of electricity.
- This principle can be used to inspire and achieve consistently satisfactory user interactions. A voice detector can automatically open and close doors without keys, which increases user satisfaction. Visual systems, including cameras and face detectors, or fingerprint recognition systems, can also be used to experience fast and continuous entrance to the apartment without the need for a key. These technologies can continuously improve user satisfaction.
- A sustainable water management system, such as a water recycling or rainwater harvesting system, reduces water usage and ensures a continuous water supply, especially in buildings built in desert areas that require constant water resources due to global warming.

6.4.21 Skipping

In construction, the skipping principle motivates designers to eliminate unnecessary, time-consuming steps. Innovative thinking creates quick construction possibilities by eliminating or bypassing unnecessary steps. Instead of making physical models, designers can visualize and modify customer building plans using augmented reality (AR). This results in faster and better visualization for non-professional customers and more efficient decision-making by eliminating physical models. Advanced construction robotics can be used instead of humans in dangerous construction sites; in this case, humans can be skipped to decrease significant hazardous situations.

Table 6.4 Creative principles numbers 21 to 30 for designers in the construction industry



6.4.22 Converting Harm into Benefit

Structural designers can get inspiration from this principle to discover creative approaches to storing seismic and lightning energy. These energies can be converted to electrical or mechanical energy instead of damaging the building. Disasters may then present an opportunity for reducing electric bills or even generating additional energy that can be sold to other buildings needing electricity. An Energy Capturing Knee Brace is designed to store energy generated by going downstairs in a building instead of damaging people's knees. This will prevent injury to the elderly resident's knee in an emergency, like deactivating elevators. This device has many examples, and it can inspire engineers (Cai, Liao, & Cao, 2018; Cai, Yang, Cao, & Liao, 2020; Gao, Liu, Fu, Li, & Liao, 2021). Descending and ascending stairs in the "Energy-Recycling Stairs" method assists in moving the energy from the person's movement down to help the individual during the climb. It makes it easier for people to climb

the stairs (Song, Ha, Hsu, Ting, & Liu, 2017, 2020). Using photocatalytic materials on building facades converts harmful air pollutants, such as nitrogen oxides, into harmless compounds during the chemical reaction. Titanium oxide is the major component of the Smog-Eating Facades. When titanium oxide is applied to a building facade, it reacts with pollutants and produces salt that will eventually be washed away by rain. They can also achieve environmental solutions by applying special nanomaterials to the facade of the building (Mohd Bukhori, 2018; Rabajczyk, Zielecka, Klapsa, & Dziechciarz, 2021).

6.4.23 Feedback

Professionals can gather valuable information and identify problems using feedback systems (Genrich Altshuller et al., 2020). Monitoring and adjusting indoor environmental conditions based on occupant feedback is called "Occupant Comfort Monitoring.". Temperature, lighting, and ventilation can all be adjusted in real time to ensure occupant comfort (Cheng, Deng, Zhao, Xiong, & Zhang, 2023; Cole & Brown, 2009; Valinejadshoubi, Moselhi, Bagchi, & Salem, 2021). The installation of energy monitoring systems that provide feedback on the energy consumption of different building systems is known as "Energy Performance Feedback." Using this feedback, building operators can identify energy inefficiencies, make informed decisions about energy-saving measures, and track the effectiveness of energy management strategies (S.-H. E. Lin & Gerber, 2014). "Structural Health Monitoring" utilizes sensors and feedback systems to monitor a building's structural health in real-time, enabling preventive maintenance and ensuring the building's safety and durability (Ko & Ni, 2005; Lynch & Loh, 2006; Sohn et al., 2003). Using sensors to monitor indoor air quality parameters such as CO₂ levels, particulate matter, and volatile organic compounds is known as "Indoor Air Quality Monitoring." Depending on the feedback received from these sensors, ventilation strategies, filters, or occupant notifications may be used to maintain a healthy indoor environment. This issue is of greater importance in hospitals than in residential buildings. It is possible to deploy several low-cost sensors coupled with a better ventilation strategy in oncology units to protect patients with compromised immune systems (Palmisani, Di Gilio, Viana, de Gennaro, & Ferro, 2021).

6.4.24 Intermediary

The "intermediary" principle can be used to introduce intermediary tools to act easily (Genrich Altshuller et al., 2020). A heavy object, for example, cannot be lifted directly. So, intermediary components, such as a lever, can be used. Using an intermediary inventive solution, navigation devices can be installed in a building that facilitates blind people's navigation. These navigation systems can be sensors, speech systems, wearable cameras, and smartphone software (Real & Araujo, 2019). Architects can introduce flexible acoustic solutions as an intermediary parameter to control sound and optimize the acoustics of interior spaces. This could involve the use of movable acoustic panels, curtains, or ceiling baffles that can be adjusted to dampen or amplify sound, depending on the function of the space (Adams, 2016). Implementing virtual reality (VR) can be used as an intermediary parameter as a research tool that can help explore user experience in a virtual model to show the actual building. VR can help users confidently choose their home design options (Kuliga, Thrash, Dalton, & Hölscher, 2015).

6.4.25 Self-Service

Necessary tasks can be performed independently using the self-service principle in designing products or systems, so manual intervention and external assistance can be decreased (Genrich Altshuller et al., 2020). Some examples of this principle in the construction industry are mentioned below. The combination of robotics and automation in construction tools causes self-service operations in the construction industry; examples of these tools are cranes and excavators. Human workers can be replaced by machines programmed with deep learning for different tasks like lifting, placing materials, and digging, which leads to improved efficiency and safety (You, Zhou, & Ding, 2023). In some crowded areas, automated parking systems use sensors and elevations for parking cars vertically without human collaboration. This technology can triple the number of parked vehicles in small spaces (Bhowmik et al., 2023).

6.4.26 Copying

Copying recommends using the best solutions from different projects or unrelated fields in the construction industry to solve your own problem (Genrich Altshuller et al., 2020). Traffic jams can be decreased using fuzzy logic copied from ant colonies. The best way to avoid high traffic can be recognized to the destination in some navigation systems for traffic management purposes (Sharif et al., 2023). Some problems, such as aerodynamic noise in high-speed elevators, are like trains. These problems can be solved by copying the aerodynamic design of high-speed trains in elevators (X. W. Wang, Yu, Zhang, Wang, & Tian, 2014).

6.4.27 Cheap Short-Living Objects

Replacement of expensive objects with cheap objects to decrease the cost of the project. However, the quality of the object is expected to be reduced. Fabrics can be used as a formwork for concrete structures instead of using ordinary metal or wooden formworks. Fabrics are more inexpensive than metal formworks, especially in complex geometry structures (Pedreschi, 2011). A temporary building-like container is an example of this principle; it is cost-effective and constructed in a short time after the disaster (Hong, 2017). PROspan structures are like tents. These buildings are easy to install and cheaper than ordinary permanent buildings. They can be used in the event of war or earthquake. This kind of structure does not need complicated permits based on codes and regulations each time occupants need to remove and reinstall them. So, their installation process is inexpensive and fast compared to ordinary buildings (Tent, 2010).

6.4.28 Mechanics Substitution

This principle recommends replacing mechanical elements in a system with optical, sound, magnetic, or electromagnetic elements or the olfactory sensors, etc., to improve the system's functionality. Here are some examples of inventive solutions using the " Mechanics substitution " principle:

Piezoelectric materials have been used in several civil engineering projects, including two applications in building dynamics and road construction. As a first example, instead of utilizing mechanical action against dynamic forces, a piezoelectric friction damper (PFD) has been used in this case instead of a mechanical damper. In addition to absorbing mechanical vibrations, piezoelectric materials in PFD generate electrical energy (KITAGAWA, TAMAI, & TAKESHITA, 2004). In the second example, pavement energy harvesting, piezoelectric materials can help convert mechanical energy into electrical energy. It is possible to utilize piezoelectric materials to convert mechanical energy into electrical energy, a dual utility that not only attracts mechanical vibrations or dynamic forces but also produces electricity. Thus, piezoelectric materials can replace mechanical methods in absorbing and converting dynamic energy rather than wasting it (Adachi, Kitamura, & Iwatsubo, 2004; Aydin & Çelebi, 2023; Benjeddou, 2000).

For soil stabilization, elastic geogrids could replace traditional soil stabilization techniques like retaining walls or piling. These geogrids are placed within the soil to provide reinforcement, reducing excavation, material, and labor costs while effectively stabilizing hillsides and slopes (Azadegan & Pourebrahim, 2010).

Traditional erosion control techniques could be substituted by biodegradable erosion control blankets made from natural fibers, leading to sustainability enhancement. They function as a temporary protection for soil from erosion while naturally degrading over time. (Gyasi-Agyei, 2004).

6.4.29 Pneumatics and Hydraulics

TRIZ Principle 29, "Pneumatics and Hydraulics," involves utilizing pneumatic (air-based) hydraulic (fluid-based) or gas or liquid-based systems instead of solid parts in a system to enhance or optimize a design or process (Retseptor, 2003). This principle can inspire innovative solutions in the building industry and civil engineering that leverage these systems for various applications. Here are some examples of inventive solutions using the "Pneumatics and Hydraulics" principle:

Viscus damper for Seismic Resilience: Instead of relying solely on mechanical bracing, use viscous damper for bracing systems that can absorb and dissipate energy during seismic events. This substitution enhances the seismic resilience of structures. To protect structures from wind and earthquake damage, viscus dampers have been used for several structures, including buildings and bridges. This technology uses fluid materials to attract vibrations (David Lee & Taylor, 2001). As a result, this principle directly inspires structural engineers and shows them how to modify ordinary bracing systems that rely on solid mechanical reactions with liquid materials contained within viscous dampers.

Construction equipment, such as excavators, could be equipped with hydraulic power transmission systems as an alternative to mechanical power transmission systems. Several advantages are associated with hydraulic power transmissions, including greater power from smaller components within construction machinery that can enhance the efficiency of heavy equipment (Hydros).

Pneumatic membrane structures like domes or inflatable roofs can provide fast and cost-effective spaces like sports stadiums or temporary structures for events by using air pressure in membrane structures (Chi & Pauletti, 2005).

6.4.30 Flexible Shells and Thin Films

TRIZ Principle 30, "Flexible Shells and Thin Films," encourages innovative use of flexible materials like films and shells to improve designs and processes. It suggests replacing the usual structure with a flexible membrane. Also, separate an object from its external environment with thin curtains of fine membrane.

Tensile Membrane Structures: Architects can design tensile membrane structures using thin, flexible materials like ETFE (ethylene tetrafluoroethylene) to create lightweight building envelopes (Lamnatou, Moreno, Chemisana, Reitsma, & Clariá, 2018; J. Schlaich, Bergermann, & Sobek, 1990).

Solar-Thermal Thin Film Collectors: Amorphous silicon is also called a thin film. It is possible to collect solar energy for heating purposes by integrating flexible solar thermal

collectors composed of thin films into building walls or roofs. In this way, renewable energy can be generated without compromising the architectural design of curtain walls or roofing materials (Kalogirou, 2004).

Shell Bridges: Engineers can design shell bridges that use different lightweight materials like stainless steel shells to span longer distances with fewer supports. The steel shell bridge could be made lighter by cutting holes inside the shell with a laser. As well as being visually striking, these bridges are also cost-effective and structurally efficient (M. Schlaich, 2018).

6.4.31 Porous Materials

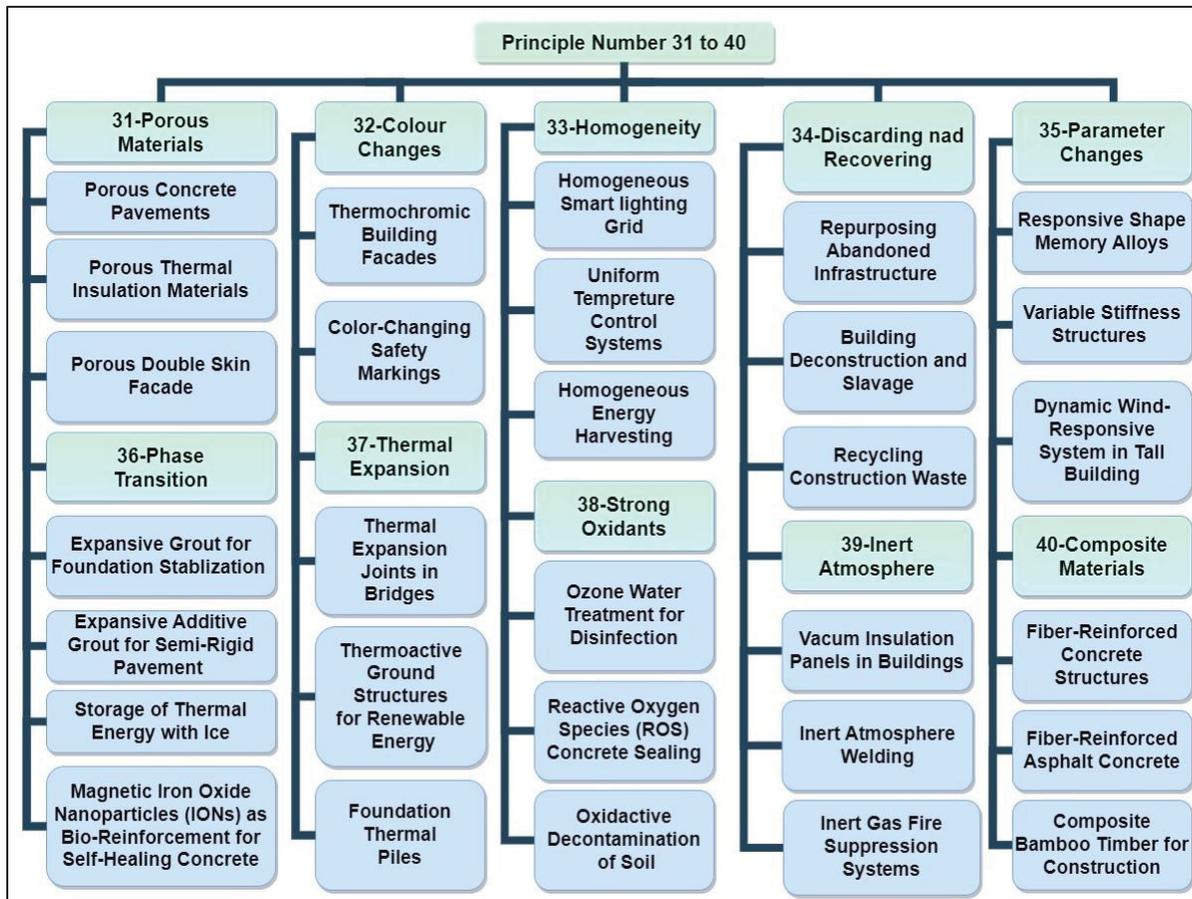
TRIZ Principle 31, "Porous Materials," describes using materials with a porous structure to improve or optimize a design or process. This principle can provide innovative solutions for improving insulation, filtration, and environmental sustainability in the construction and civil engineering industries. The following are a few samples of creative approaches that apply the "Porous Materials" principle:

Porous Concrete Pavements: Pavements can be constructed using porous concrete. Compared to ordinary concrete, porous concrete has about 20 percent less strength. Heavy vehicles are not permitted to pass on porous concrete. Moreover, pedestrians present only a minor dynamic load to pavements, so these forces would not cause cracks in the pavement. The pavement surface does not typically absorb much water. Hence, the solution to this problem is to use porous concrete in pavements to facilitate underground rainwater transfer. Consequently, climate change and heavy rainfall may not result in floods (Moretti, Di Mascio, & Fusco, 2019).

Porous Thermal Insulation Materials: Polyurethane foam (PUF), which is lightweight and low density, is one of many porous thermal insulation materials (PTIMs) used in the construction, hydropower, and water conservation industries. As a result of their low thermal conductivity, they are also heat resistant. The mechanical properties of these materials are also superior (Z. Wang et al., 2023).

Porous Double Skin Facade: Porous materials could be used as an energy isolator in the building. Building facades with porous double skins is increasingly useful due to their high energy efficiency (Pomaranzi, Daniotti, Schito, Rosa, & Zasso, 2020).

Table 6.5 Creative principles numbers 31 to 40 for designers in the construction industry.



6.4.32 Color Changes

According to TRIZ Principle 32, "Color Changes," it is possible to improve a design or process by changing the color of an object or component. In addition, this principle may inspire designers to change the element's transparency. Furthermore, it is recommended that colored additives be used to make objects that are difficult to see more visible. Consider using luminous signs or tracer components if such additives are already used. This principle can inspire innovative solutions in the building industry and civil engineering that enhance aesthetics,

functionality, and safety. Here are a few examples of inventive solutions using the "Color Changes" principle:

Thermochromic Building Facades: The use of thermochromic materials in building facades can change the exterior's color according to the temperature. During rising or falling temperatures, the building's appearance shifts, which assists in passively regulating interior temperatures and reduces the need for active climate control (Y. Zhang & Zhai, 2019).

Color-Changing Safety Markings: Applying color-changing coatings or materials to safety markings on roadways, bridges, and tunnels can improve visibility and safety. For instance, these markings can change color in response to specific conditions like icy roads, alerting drivers to potential hazards (Dumé, 2008).

6.4.33 Homogeneity

To improve the performance or reliability of objects or systems, TRIZ Principle 33, "Homogeneity," suggests enhancing their uniformity or consistency. In the building industry and civil engineering, this principle can inspire innovative solutions that promote structures' integrity, durability, and efficiency. Following are a few examples of inventive solutions based on the "Homogeneity" principle:

Homogeneous Smart Lighting Grid: The lighting system should be designed to provide consistent illumination throughout the building, ensuring occupant well-being and energy efficiency (Williams, Atkinson, Garbesi, Page, & Rubinstein, 2012).

Urban lighting consumes a significant amount of electrical energy. As a result, the Lighting Smart Grids (LSG) work lines suggest introducing energy efficiency strategies by high-efficiency LED devices with continuous regulation capabilities in lighting systems. By incorporating control strategies to fit the needs of citizens, traffic, or the city in real-time, wireless technologies (Wi-Fi, ZigBee, Li-Fi, etc.) present a significant opportunity for new features and unthinkable benefits in this context. A new concept for urban lighting systems with a high level of customization is presented in this paper while also incorporating wireless

lighting strategies as a part of the design (Martin-Arias, Huerta-Medina, & Rico-Secades, 2013).

Uniform Temperature Control Systems: Ensure that HVAC systems are equipped with sensors and controls that provide a homogeneous distribution of temperatures within a building, thus ensuring that the environment is comfortable and energy efficient. Traditionally, the heating, cooling, lighting, and blinds associated with zone-level offices have either been controlled by occupants or automated by setpoints and schedules set by the building manager. Typically, the occupants control the operation of these systems to maintain a comfortable indoor environment with the least amount of control actions while attempting to save as little as possible energy. As a result, daylight and passive solar heat gain are not fully utilized. Most operators, however, choose conservative setpoints and schedules when they are automated to mitigate the extravagance in occupant behavior and minimize complaints with little regard to energy savings. While building controllers have traditionally been treated as our servants, maintaining fixed setpoints and schedules, they represent an excellent opportunity for implementing distributed artificial intelligence. A tool for adaptive indoor climate control was developed within the scope of this thesis. A novel algorithm is included in the tool that recursively learns from occupancy patterns and adapts occupant behavior to develop an inverse model of the heat transfer problem in each zone. A few low-cost building sensors were used in conjunction with the algorithms to undertake the learning process in real time. According to the data derived from the occupants and the temperature response of the building, an autonomous system was used to choose operating setpoints and schedules based on nuances within different subspaces in the structure. A control laboratory with a dedicated control network was set up to implement and test the algorithms for over a year. Additionally, they were implemented and tested in private offices for nearly a year. Several alternative scenarios related to these algorithms were analyzed through energy consumption and daylighting simulations. The results of this thesis indicate that adaptive indoor climate control algorithms can significantly reduce space heating, cooling, and lighting loads in office buildings without adversely affecting the comfort of occupants. As a result of the simulation results, adaptive control of the indoor climate results in lower load intensities and reduces the probability of

poor operational decisions that can lead to discomfort and excessive energy consumption (Gunay, 2016).

Homogeneous Energy Harvesting: Integrated building renewable energy systems that uniformly provide energy from various sources are called homogeneous energy harvesting. These systems include solar panels, wind turbines, photovoltaic systems, rainwater harvesters, natural ventilation, and roof-sky lighting for maximum energy savings (Chong et al., 2016).

6.4.34 Discarding and Recovering

The TRIZ Principle 34, "Discarding and Recovering," emphasizes finding innovative solutions by identifying components or elements that can be discarded or eliminated from a system and then identifying ways to recover value from these components. The following are some examples of inventive solutions using the concept of "discarding and recovering" in the construction industry and civil engineering:

1. **Repurposing Abandoned Infrastructure:** Consider repurposing old infrastructure, such as railways or industrial sites, rather than abandoning them. It is possible, for example, to convert abandoned rail corridors into walking and biking trails, which contributes to preserving valuable land and infrastructure (Finucane & Tarnowy, 2019).
2. **Building Deconstruction and Salvage:** Deconstruction and salvage processes are preferable to demolishing entire buildings. This method carefully dismantles structures so that reusable materials, including structural steel, bricks, and architectural elements, can be harvested for use in new construction or renovation (Shami, 2006).
3. **Recycling Construction Waste:** There is a significant amount of waste generated by construction sites, including concrete, wood, and metal. Recycling programs can help reduce landfill waste and conserve resources for future projects by recovering valuable materials from discarded construction components (Ibrahim, 2016).

6.4.35 Parameter Changes

In TRIZ Principle 35, "Parameter Changes," the goal is to enhance a system's or design's performance or functionality by changing one or more parameters. Applying this principle in

the building industry and civil engineering can facilitate the development of innovative solutions that optimize various construction, operation, and maintenance aspects. A few examples of inventive solutions based on the "Parameter Changes" principle are listed below:

1. **Responsive Shape Memory Alloys:** Shape memory material (SMM) is a common type of intelligent multifunctional material used in civil engineering applications since it can recall its original shape after being molded. They can regain their original shape under stimuli, such as heat, if deformed. Shape memory materials can be classified into four types: alloys, polymers, magnetic materials, and ceramic materials. Various applications can be made with these multifunctional materials, including actuators, structural health monitoring, and self-healing products (Abavisani, Rezaifar, & Kheyroddin, 2021). Adaptive seismic resistance can be achieved by integrating shape-memory alloys into structural elements, such as dampers (Clark, Aiken, Kelly, Higashino, & Krumme, 1995).
2. **Variable Stiffness Structures:** It is possible to design structures with adjustable stiffness using semi-active tuned mass dampers with adaptive stiffness properties or active control of structures. The structure displacement can be predicted in advance using fuzzy logic and neural networks, and failure is avoided through semi-active systems by altering the response of the building to dynamic loads in real-time (L. Wang, Zhou, & Shi, 2023; Han Zhang, Wang, & Shi, 2023).
3. **Dynamic Wind-Responsive System in Tall Buildings: Double-skin** facades can potentially control tall buildings' dynamic loads (wind). Wind energy is filtered by the outer skin, which significantly impacts the response of the primary structure. Using connectors with adjustable stiffness can control the primary structure response by limiting the movement of the outer skin of the facade as much as possible (Azad, Ngo, & Samali, 2015).

6.4.36 Phase Transition

According to TRIZ Principle 36, "Phase Transition," changing the phase of a substance or system can lead to specific improvements in design or performance. Volume changes, heat

loss, and absorption can result from phase transition phenomena. Building industry and civil engineering practitioners can use this principle to develop innovative solutions that improve energy efficiency, structural integrity, and functionality. Using the "Phase Transition" principle, we can come up with the following inventive solutions:

- 1. Expansive Grout for Foundation Stabilization:** Stabilizing Foundations can be stabilized using expansive grout that undergoes phase transitions during curing. Since this grout expands as it changes phases, it provides structures with increased stability by filling in cracks and voids in the soil. Many foundation issues can be caused by soil subsidence, including slab foundation cracks, building settlement, and wall cracking (US, 2024). An expandable polyurethane resin is suitable for soil injection, which provides an innovative method for compensating settlements and uplifting and stabilizing the foundations of previously constructed structures and buildings (Sabri, Vatin, & Alsaffar, 2021). In addition to this material, expandable foam grout (EFG) can be used as a repair material to address this issue (W. Han, Lee, Jeong, Lim, & Byun, 2021).
- 2. Expansive Additive Grout for Semi-rigid Pavement:** Asphalt concrete cracks, plastic deformation, and potholes increase life cycle costs for roads. Pavement construction companies need to find a quick solution to this problem. Calcium silicate aluminate (CSA), which can harden rapidly and expand in volume after hardening, can be used to repair potholes and cracks in concrete pavements. Using these cement additives to repair cracks and potholes in concrete pavements is beneficial since they can expand to fill the gaps completely (B. J. Lee, Bang, Jang, Kim, & Kim, 2014).
- 3. Storage of thermal energy with ice:** To reduce peak electricity demand, ice storage systems can be implemented for cooling. When electricity is not used during peak hours, water is frozen. When electricity is in use during peak hours, stored ice is melted to cool the air or water. This improves energy efficiency and reduces operating costs for commercial and residential buildings (Wu, Feng, & Tsai, 2015).
- 4. Magnetic iron oxide nanoparticles (IONs) as bio-reinforcement for self-healing concrete:** The use of nanomaterial additives, such as IONs, can lead to self-healing phase transitions within concrete, eliminating cracks (Seifan et al., 2018).

The "Phase Transition" principle inspires building and civil engineering professionals since it recognizes that materials and systems can undergo physical changes that contribute to improved performance, sustainability, and functionality. Using phase transitions in construction and infrastructure projects can provide innovative solutions to thermal comfort, energy efficiency, structural resilience, and environmental impact challenges.

6.4.37 Thermal Expansion

TRIZ Principle 37, "Thermal Expansion," involves utilizing the property of materials to expand or contract with temperature changes to improve design or performance. This principle can inspire innovative solutions in the building industry and civil engineering that optimize structural integrity, energy efficiency, and functionality. Here are a few examples of inventive solutions using the "Thermal Expansion" principle:

1. **Thermal Expansion Joints in Bridges:** Using thermal expansion joints allows bridges to expand naturally. As the temperature changes, bridges can expand, and these expansions need to be controlled by expansion joints or other tools to prevent cracks and bridge destruction (Roeder & Moorty, 1991). It is recommended that the bridge deck temperature be considered when specifying the expansion gap width on the contract drawings. A bolt-down panel is constructed with different widths to the range of movement allowed (Dornsife, 2019).
2. **Thermoactive ground structures for renewable energy:** Foundations and other thermoactive ground structures can absorb geothermal energy. Installing absorber pipes filled with a heat carrier fluid underground is possible. The natural ground temperature provides summer cooling and winter heating. The ground can transfer heat to the air by absorbing fluid (Brandl, 2006).
3. **Foundation Thermal Piles:** A building's foundation system can be directly affected by differential movements caused by thaw settlement or frost heave in ice-rich soils (Government of Canada-Submitted By: AGRA Earth & Environmental Limited, 2000). Cast-in-place pile foundations support many buildings in frozen regions. Thermal

regime changes in permafrost can affect pile foundation stability significantly. As permafrost continues to erode, cast-in-place pile foundations are at greater risk of disaster. However, proactive cooling methods for cast-in-place pile foundations rarely can be found in the literature. It is important to note that two-phase closed thermosyphons (TPCTs) produce cold energy to prevent permafrost thermal shifts caused by climate change. TPCTs were installed within a concrete pile to create a thermal pile (Shang, Niu, Yuan, Sun, & Wu, 2023).

As an inspirational principle in the building industry and civil engineering, the "Thermal Expansion" principle exploits the intrinsic properties of materials to address various challenges. To enhance structural resilience, energy efficiency, and adaptability in the built environment, engineers and designers should be able to understand and creatively apply thermal expansion. As a consequence of this principle, simple, passive mechanisms are encouraged to improve the system's efficiency through temperature-related changes.

6.4.38 Strong Oxidants

The TRIZ Principle 38, "Strong Oxidants," involves using substances with strong oxidizing properties to improve the performance of a system or solve specific problems. This principle can inspire innovative solutions in the construction industry and civil engineering that will enhance durability, sanitation, and environmental sustainability. The following are examples of inventive solutions using the "Strong Oxidants" principle:

1. **Ozone Water Treatment for Disinfection:** Implementing ozone water treatment systems in buildings can provide effective disinfection for potable water supplies. Ozone is a strong oxidant that kills bacteria and viruses, ensuring safe and clean drinking water (W. Ding et al., 2019).
2. **Reactive Oxygen Species (ROS) Concrete Sealing:** Applying ROS-based sealants to concrete surfaces can enhance their durability and resistance to environmental factors. These sealants form a protective layer that reacts with atmospheric oxygen to create a hard and durable surface (Yin et al., 2021).

3. **Oxidative Decontamination of Soil:** Using strong oxidants like potassium permanganate or hydrogen peroxide can remediate contaminated soil. These chemicals oxidize and neutralize pollutants, making the soil suitable for construction or redevelopment (Calenciuc et al., 2022).

6.4.39 Inert Atmosphere

TRIZ Principle 39, "Inert Atmosphere," involves using an environment devoid of reactive gases to improve a system's performance or address specific challenges. In the building industry and civil engineering, this principle can inspire innovative solutions that enhance material preservation, reduce corrosion, and improve safety. Here are a few examples of inventive solutions using the "Inert Atmosphere" principle:

1. **Vacuum Insulation Panels in Buildings:** Incorporate vacuum insulation panels within concrete walls. This creates an inert environment that reduces heat transfer, improving the energy efficiency of buildings (Baetens et al., 2010; Johansson, 2012).
2. **Inert Atmosphere Welding:** Employing inert gas welding techniques, such as tungsten inert gas (TIG) welding or gas metal arc welding (GMAW), can reduce the risk of corrosion in welded joints. The protective atmosphere prevents the formation of oxidation layers on the weld, ensuring strong and durable connections (Dinbandhu, Vora, & Abhishek, 2021).
3. **Inert Gas Fire Suppression Systems:** Installing inert gas-based fire suppression systems in critical infrastructure or data centers can quickly extinguish fires while preserving sensitive equipment. These systems displace oxygen with inert gases to suppress fires without causing damage from water or traditional firefighting chemicals (Atukpawu, 2022; Junjunan et al., 2021; White, Dietenberger, & Wood Handbook, 1999).

The "Inert Atmosphere" principle is inspirational in the building industry and civil engineering because it introduces the concept of creating controlled environments to protect materials, equipment, and structures. By creatively applying inert atmospheres, professionals

can develop inventive solutions that enhance safety, preserve valuable assets, and extend the lifespan of critical infrastructure. This principle encourages a proactive environmental control and preservation approach within various construction and engineering contexts.

6.4.40 Composite Materials

TRIZ Principle 40, "Composite Materials," involves using combinations of materials with different properties to improve design, durability, and performance. In the building industry and civil engineering, this principle can inspire innovative solutions that enhance structural integrity, reduce weight, and increase sustainability. Here are a few examples of inventive solutions using the "Composite Materials" principle:

1. **Fiber-Reinforced Concrete Structures:** Incorporating fibers made of materials like glass, carbon, or polypropylene into concrete mixtures enhances tensile strength and crack resistance. This composite material improves the durability of concrete structures such as bridges and high-rise buildings (Uygunoğlu, 2008).
2. **Fiber-Reinforced Asphalt Concrete:** Enhance asphalt mixes with fiber-reinforced composite materials, combining the flexibility of asphalt with the strength and crack resistance of fibers for longer-lasting road surfaces (Guo et al., 2020).
3. **Composite Bamboo Timber for Construction:** Utilize composite materials that combine bamboo fibers with polymers to create a sustainable alternative to traditional timber, offering high strength, durability, and resistance to pests (Chen, Wei, Ding, Zhao, & Zheng, 2022).

The "Composite Materials" principle is inspirational in the building industry and civil engineering because it encourages professionals to consider the synergistic properties of materials. Combining materials with distinct strengths can lead to innovative solutions that improve structural performance, durability, and sustainability. Composite materials offer versatility and customization, enabling engineers and designers to optimize solutions for specific challenges and applications in construction and infrastructure projects.

6.5 Mobile Application

A mobile application is designed based on our previous work, including Archi-TRIZ, a dedicated matrix for the building design industry. The Archi-TRIZ contradiction matrix is used to design a non-structural component in the building to examine its performance. This was very effective in expanding our creativity in designing building components. Archi-TRIZ assigned each contradiction several inventive principles that were most repetitive and effective. Based on the previous mobile application, when the contradiction is chosen, the mobile application displays the recommended inventive principle numbers (Hassanijajini et al., 2024). In addition to that mobile application, designers of buildings need to be familiar with inventive principles within the building design industry. This is necessary to think of creative ideas effectively. To fill this research gap, the purpose of this article is to provide examples of existing inventions and their connections to each of the inventive principle number (IPN) 1 to 40 in the building industry that can be added to a mobile application or website to facilitate building designers' innovative solutions by mimicking these examples.

Mobile applications and websites can be designed to show the possible examples of principle number 1 to 40 in architectural design and structural design of the building in the construction industry. A description of the specific principle with several examples in different fields of the construction industry can be shown in each line section to give an idea to the designers to get more inspiration in the building design process.

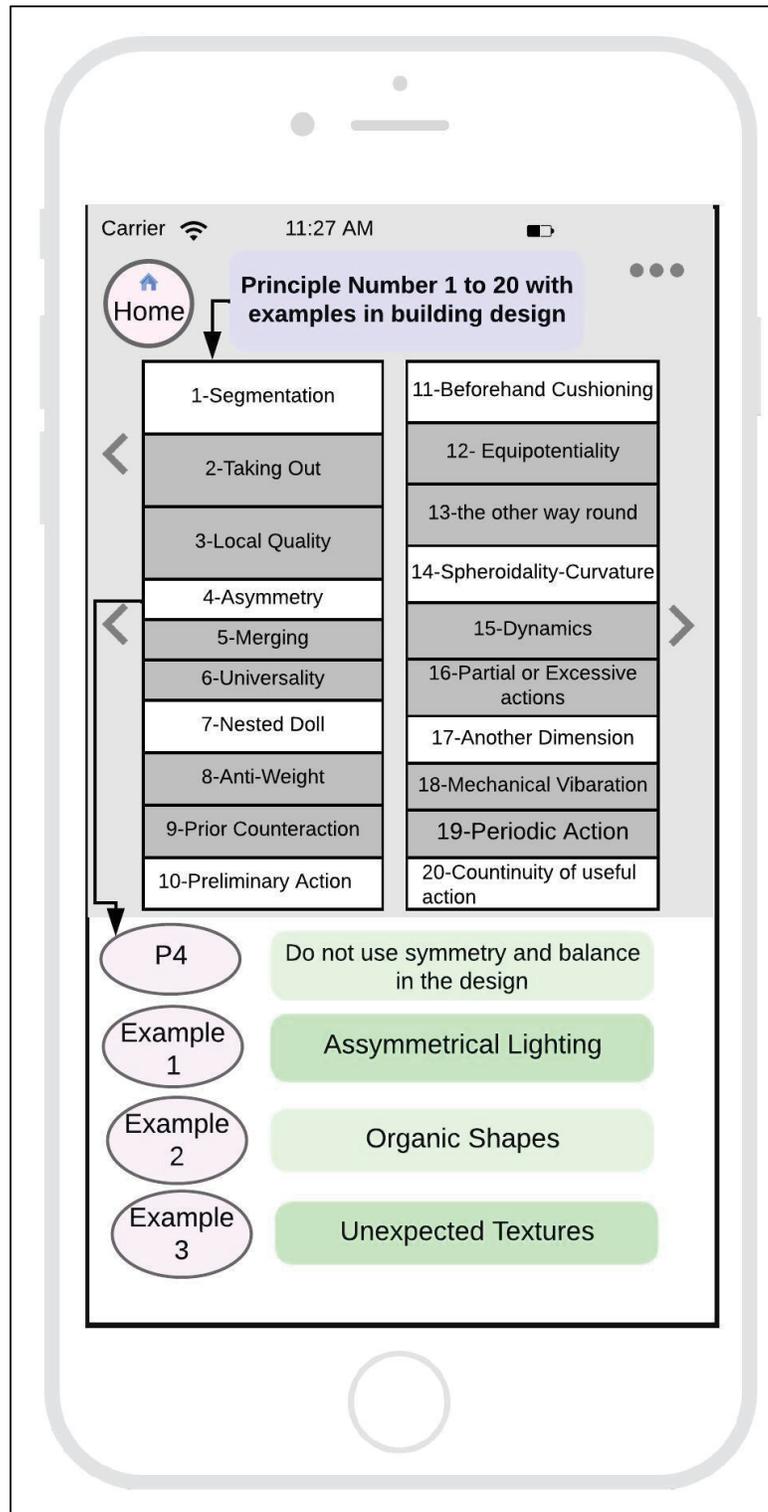


Figure 6.1 Mobile application and website can be designed

It is possible to add some pictures like figures to this mobile application or website to demonstrate the idea of inventive examples to the designers.

6.6 Conclusions

To give building designers unfamiliar with TRIZ a viewpoint and increase the possibility of innovative solutions during the building design process, the mobile application is designed to introduce inventive solutions with descriptions for each inventive principle.

6.7 Research Benefits, Industrial Impact

In the building design process, this newly introduced application could be easily used by civil engineers, structural engineers, and architects, allowing them to utilize the TRIZ principle number 1 to 40 more efficiently by getting inspired by the inventive examples of each TRIZ principle. The building design industry could benefit from this to boost innovation.

6.8 Future Works

There are many fields in the construction and building design process, such as earthquake engineering, architectural design, environmental engineering, project management, soil and foundation engineering. These examples could be included in the mobile application or website to inspire engineers. Several categories can be added to this mobile application. As a result, when an engineer selects a field of engineering, he will only be able to see the examples that apply to that field. The application would then be more wide-ranging and complete, requiring team collaboration. This could be considered as a future work for this paper.

CHAPTER 7

A SYSTEMIC INTEGRATED APPROACH TO ACHIEVE OPTIMAL CHOICE REGARDING END USERS' NEEDS BY COMBINING ARCHI-TRIZ AND QFD FOR BUILDING DESIGN PROCESS

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7.1 Abstract

This study introduces a systemic integrated method that combines Quality Function Deployment (QFD) and a customized TRIZ Matrix (Archi-TRIZ) for the building design process. The goal is to achieve appropriate choices regarding end users' needs by translating customer requirements into design parameters, thus enhancing innovation and decision-making in construction. The methodology adapts the traditional TRIZ matrix specifically for building design, Archi-TRIZ, and integrates it with QFD, providing a framework to improve the evaluation of engineering requirements for validating design concepts.

Although QFD and TRIZ have been widely applied across various industries, their use in construction, particularly in non-structural and interior design components, remains limited. This research addresses this gap by using Archi-TRIZ and testing its effectiveness in real-world applications.

In a previous research, the utility of Archi-TRIZ in designing innovative components for movable walls was examined. In this paper, it is emphasized that by gathering the Voice of Customer (VOC), more customer-desired components could be selected for the movable wall, aiming to commercialize it. This combined methodology of Archi-TRIZ and QFD will assist in developing a better product that aligns with user needs and enhances project outcomes.

7.2 Introduction

Altshuller developed a contradiction matrix called TRIZ (Theory of Inventive Problem Solving). TRIZ operates as a systematic innovation methodology designed to resolve technical contradictions. It is a tool derived from 40,000 inventions. It includes 40 inventive principles, 39 worsening features, and 39 improving features. Its theory states that when one feature is improved, another feature worsens. TRIZ resolves this contradiction by introducing several inventive principles through its 40 inventive principles. The designer, by observing these principles and focusing on examples, could be inspired to generate innovative solutions to resolve the contradiction. Inventive ideas could help the designer improve one feature without worsening another, optimizing engineering processes (Ekmekci & Nebati, 2019; Renev & Chechurin, 2016).

		ENGINEERING PARAMETERS WHOSE DETERIORATION MUST BE AVOIDED				
		1	...	17	...	39
	WEIGHT OF A MOBILE OBJECT			6, 29, 4, 38		35, 3, 24, 37
	...					
	SPEED	8, 28, 13, 38		28, 30, 36, 2		-
	...					
	CAPACITY / PRODUCTIVITY	35, 26, 24, 37		35, 21, 28, 10		

Figure 7.1 Summary of TRIZ
Taken from Naveiro and Oliveira (2018)

As shown in Figure 7.1, if “speed” should be improved and the designer wants to avoid worsening the feature “weight of the moving object,” then TRIZ recommends using Inventive

Principles No. 8 (Anti-weight), 28 (Mechanics substitution), 13 (The other way round), and 38 (Strong oxidants) to help designers get inspired and introduce innovative solutions to increase speed without worsening the “weight of the moving object” in order to solve the contradiction.

As it was indicated in previous studies, the absence of enough applicability of TRIZ in the building field is a considerable concern. A literature review in this field was also conducted. In order to increase innovation in the design, a specialized matrix is needed (Hassanijajini & Gardoni, 2022). Then, Archi-TRIZ contradiction matrix has been introduced that could be used and accelerate the innovation in the design building process (figure 7.2) (Hassanijajini et al., 2024).

	Dimensions and physical characteristics of the BNSC (1,3,5,7,12)	Speed and time (9,25)	Strength and stability of BNSC (10,11,13,21)	Durability of the BNSC (14,27,29,30,31)	Energy (17,18,19,20,22)	Ease of use and user satisfaction (33,35,37,38)	Builder convenience (32,34,36)
Dimensions and physical characteristics of the BNSC (1,3,5,7,12)	+	29,10,8,15,20,38	10,35,1,(18,36,37,33,21,31)	40,1,35,(14,28,22,2,33,39,9,30,7,11,31)	15,19,32,2,(34,35,39,7,31,38)	15,26,29,(35,1,24,30)	1,28,13,26,(11)
Speed and time (9,25)	34,29,10,2,(13,4,5,35,20,7,38)	+	35,6,(5,10,19,28,36,37,38,20,33)	35,28,18,(3,24,26,11)	35,19,18,1,(5,20,38)	28,10,(18,32,34,35)	28,34,(1,4,10,35)
Strength and stability of BNSC (10,11,13,21)	10,35,15,36,(31,9,11,38)	35,36,15,(10,28,37,6,20,33)	+	35,27,18,2,(9,11,33)	2,10,14,16,19,35,(25,38)	35,2,17,19,(30,20,11)	35,10,1,(2,19,26,20,11)
Durability of the BNSC (14,27,29,30,31)	1,10,15,22,35,40,(8,4,9,7,23,30,11,33)	28,35,10,(3,18,21,22,26,32,11)	35,18,2,10,3,28,(30,11,31,33)	+	35,2,19,32,10,22,(24,21,11,33)	27,40,2,(3,15,32,35,25,23,11,31,33)	2,1,10,11,35,(25,31)
Energy (17,18,19,20,22)	19,18,32,15,(2,6,12,13,28,7,30,31)	35,18,19,(10,28,38,7)	19,2,32,35,21	35,2,19,22,3,1,2,1,33	+	35,2,19,(15,26,31)	28,2,16,17,26,7
Ease of use and user satisfaction (33,35,37,38)	1,13,15,17,35,(16,28,29,7)	28,35,10,(4,34)	35,30,2,(1,28,32,20,39)	28,32,2,27,35,(3,8,40,23,31,1,1,33)	13,19,35,2,(1,26,38)	+	1,13,26,(13,28,12,5,7,11,31)
Builder convenience (32,34,36)	1,13,26,28,29,(11)	34,1,10,28,35	1,19,35,2,(12,20,11)	1,2,11	1,13,27,28	1,15,28,13,16,(7,11)	+

Figure 7.2 Archi-TRIZ Matrix for Building Nonstructural Components’ Design Process Taken from Hassanijajini et al. (2024)

Archi-TRIZ, is a customized matrix derived from the original TRIZ methodology, aimed at accelerating innovation in building design, particularly for building non-structural components (BNSCs) (Hassanijajini et al., 2024). The matrix condenses the 39 features from the traditional

TRIZ into seven features, which focus on improving one feature while minimizing negative impacts on others.

Key points of Archi-TRIZ (Hassanijajini et al., 2024):

- Archi-TRIZ adapts the inventive problem-solving principles of TRIZ to architectural design.
- It helps designers resolve contradictions in BNSC design by recommending inventive principles.
- The matrix has been validated through examples, such as foldable wall systems for flexible apartment layouts.
- The method is not limited to architecture but could be applied across various civil engineering fields to inspire creativity and solve engineering challenges.
- While Archi-TRIZ provides inventive solutions and design options, it lacks the capability to prioritize and select the optimal solution based on specific customer needs. To address this limitation, the integration of Quality Function Deployment (QFD) could be employed.
- QFD is particularly effective in helping designers in decision-making by evaluating and ranking design characteristics according to customer preferences, it could be able to ensure a more customer-centric design approach.

The QFD concept was introduced in Japan to design production without copying and increase the originality of the production by considering the needs of the customer.

QFD prioritizes customer-driven engineering by identifying key requirements, establishing relationships between these needs and technical solutions, and guiding decision-making to increase quality and customer satisfaction(Wolniak, 2017)

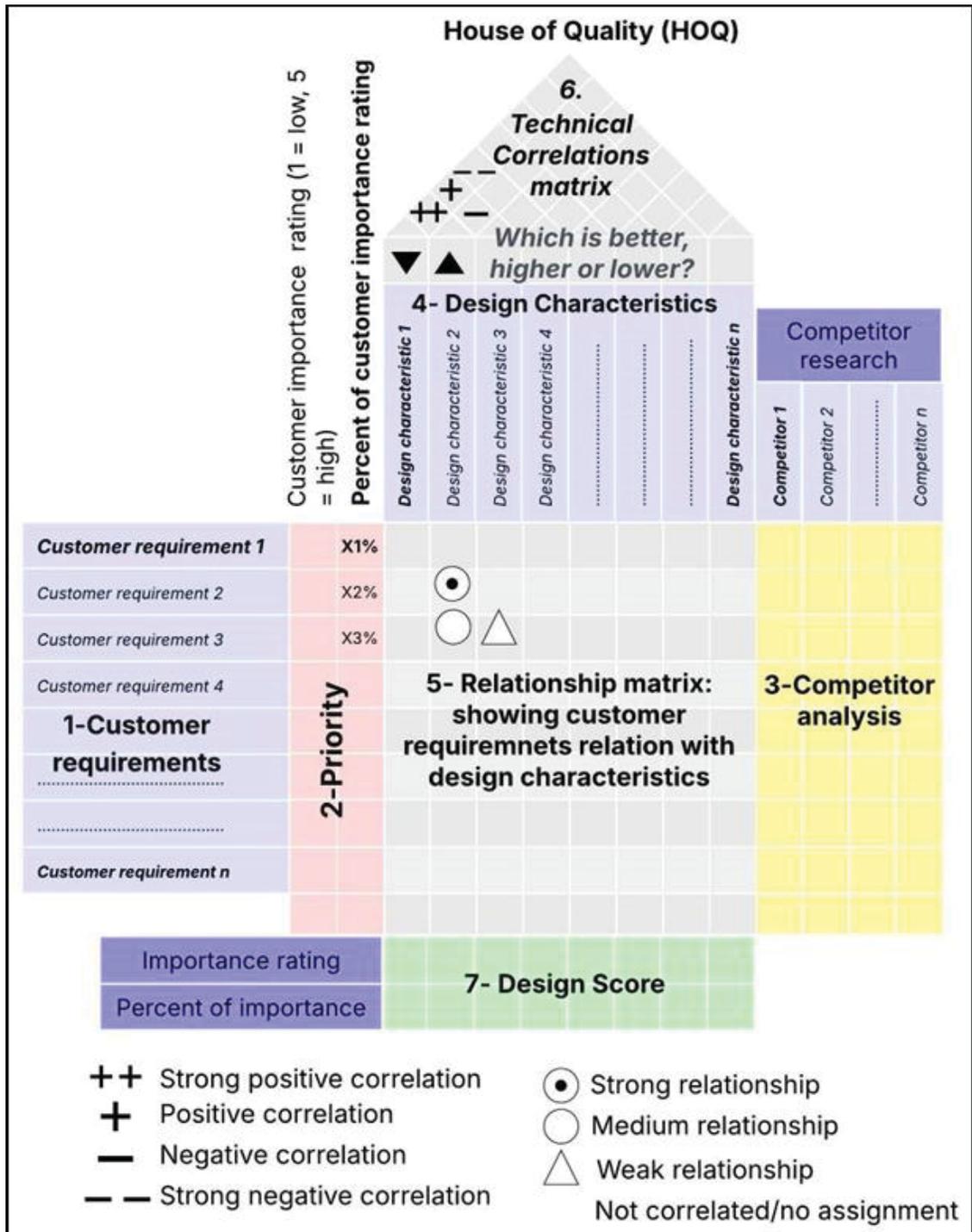


Figure 7.3 House of Quality (HOQ)
Francis (2016); Hauser and Clausing (1988)

As illustrated in Figure 7.3, the House of Quality (HOQ) includes seven features. The first feature is customer requirements. The second feature is the importance score of each customer requirement, which helps prioritize the requirements based on their significance. The third feature is competitor analysis, which shows how successfully each competitor addresses the customer requirements. Engineers have to translate the voice of the customer into design characteristics. Feature 4, as shown in Figure 7.3, represents these design characteristics—the voice of the engineer. Feature 5 shows the relationship between customer requirements and design characteristics. Feature 6 is the technical correlation matrix, which has been removed to simplify our research methodology. Feature 7 is the design score, which ranks the proposed options to help select the better solution (Erdil & Arani, 2019; Hauser & Clausing, 1988; Park & Kim, 1998; Salimi, 2022). Some researchers, such as Sina Salimi and Mickael Gardoni, have used C-K theory first and then applied QFD as the second methodology. This allows designers to invent more freely and creatively, enabling them to explore available inventive solutions for each feature of the product. They then used the ranking system of the House of Quality (HOQ) to select the better option for each feature. In their thesis, the correlation matrix of the HOQ was removed to simplify the utility of QFD (Salimi, 2022).

In our methodology, the Archi-TRIZ and HOQ could be used multiple times to maximize customer satisfaction. This approach allows for greater consideration of customer requirements without restricting the creativity of designers in an open innovation environment. For these reasons, we did not use QFD with the correlation matrix before TRIZ. Instead, we adopted a simplified and customized method to support innovation for designers and civil engineers.

Although many researchers have first used QFD and then identified contradictions through the correlation matrix before applying TRIZ, this approach often introduces unnecessary complexity. It tends to limit the designer's freedom in proposing multiple innovative ideas and is generally not well-received by civil engineers, as it could cause confusion and overwhelm the design process with too many influencing factors. This could discourage inventors from developing further solutions (Al-Dwairi, Al-Araidah, & Hamasha, 2023).

The reason we applied Archi-TRIZ first was to give designers the freedom to explore and propose inventive solutions. Then, by adding some technical features and using QFD to rank and evaluate those options, the process is guided toward selecting a solution that is both innovative and responsive to customer needs. We also acknowledge that this process could be repeated to add more detail based on customer requirements and further improve satisfaction. Removing the correlation matrix in QFD and customizing TRIZ into Archi-TRIZ was aimed at making these tools more accessible and practical for building designers. Since the direct use of traditional QFD and TRIZ could be challenging for non-experts in these methods, we aimed to develop a faster, simpler, and more user-friendly approach to support innovation in the construction field.

Some researchers, such as Hongyi Zhang and Liang Su, introduced a combination of QFD, TRIZ, and an optimization algorithm. They used QFD first to gather customer requirements, then applied TRIZ to solve technical contradictions by utilizing the inventive principles of TRIZ to find innovative approaches, and finally used a multi-objective mathematical algorithm for optimization. This combined method was tested on a satellite to design its solar panel, aiming to reduce costs and improve durability and power. As a result, the cost of the solar panel was reduced by 12.5%, while its power ratio, reliability, and operational lifespan increased by 20.8%, 0.04%, and 39.4% respectively (Hongyi Zhang & Su, 2025). Seri Oh et al. also developed a modular building that could be exported using QFD and TRIZ. They reduced the weight and volume of the modular building by 30% and 48%, respectively, to facilitate easier export (Oh et al., 2017). In fact, TRIZ had better performance in industry when combined with other methods like QFD. This research proposes an integrated approach that combines Archi-TRIZ (Hassanijajini et al., 2024) with QFD to address the design needs of end users in the construction industry. The integration aims to systematically translate customer requirements into actionable design parameters, thereby enhancing innovation and efficiency in the building design process. Current literature indicates a research gap in the application of these methodologies within the construction sector, particularly concerning non-structural and interior design components. The objective of this study is developing a QFD tailored for moveable wall design, considering customers' needs in producing detailed and additional parts for innovative solutions by utilizing Archi-TRIZ.

There are so many researches that combined TRIZ with QFD to boost innovation-based products by considering customer needs in different fields (Caligiana et al., 2017; Kim, Lim, & Cho, 2022; Naveiro & Oliveira, 2018; W. Yang, Cao, Peng, & Sun, 2021). While the keyword is limited to building design, the number of articles dramatically decreases (Molina & Desai, 2023; Oh et al., 2017). When the word Archi-TRIZ with QFD is searched together, there is no article.

Archi-TRIZ helps building designers in accelerating innovation by resolving contradictions and generating multiple inventive solutions. However, to facilitate decision-making, evaluate which inventive solution aligns better with customer needs, and incorporate additional features into the product, the integration of QFD becomes essential as a second phase.

7.3 Methodology

This methodology includes two different phases. The first phase is the creativity process. In this phase, it is possible to use Archi-TRIZ to create inventive designs. Since TRIZ and Archi-TRIZ are systematic methodologies for resolving contradictions and generating inventive solutions, they are particularly useful in the creativity phase for creating inventive designs. For example, in the movable wall example from our previous study, there are n options based on a creative movable wall example visible in the figure 7.5 (Hassanijajini et al., 2024). It is needed to choose which option is better by considering customer needs and adding more features to the product to maximize quality and customer satisfaction. So, the second phase (figure 7.6) involves creating the QFD matrix which focuses on gathering and analyzing the Voice of the Customer (VOC), translating customer needs into product specifications that guide the design. Essential components are then identified, with critical components specified and design options considered. The second phase involves selecting components based on detailed analysis and rankings, integrating them into the manufacturing and assembly processes to ensure the product meets customer requirements efficiently. In this phase, the designer also decides which of the two movable walls is more acceptable to the customers.

In the figure 7.4, Archi-TRIZ application has been demonstrated, and several types of movable walls (figure 7.5) have been presented to showcase the matrix's capability to expedite

innovation in the building design process (Hassanijajini et al., 2024). In this phase, several options could be designed using Archi-TRIZ for the product through innovative approaches. The customers' needs that were identified could be used to better design each system characteristics which called system characteristics in figure 7.7.

Worsening Feature Improving Feature	Dimensions and physical characteristics of the BNSC (1,3,5,7,12)	Speed and time (9,25)	Strength and stability of BNSC (10,11,13,21)	Durability of the BNSC (14,27,29,30,31)	Energy (17,18,19,20,22)	Ease of use and user satisfaction (33,35,37,38)	Builder convenience (32,34,36)
Dimensions and physical characteristics of the BNSC (1,3,5,7,12)	+	29,10,8,15,20,38	10,35,1,(18,36,37,33,21,31)	40,1,35,(14,28,22,2,33,39,9,30,7,11,31)	15,19,32,2,(34,35,39,7,31,38)	15,26,29,(35,1,24,30)	1,28,13,26,(11)
Speed and time (9,25)		+	35,6,(5,10,19,28,36,37,38,20,33)	35,28,18,(3,24,26,11)	35,19,18,1,(5,20,38)	28,10,(18,32,34,35)	28,34,(1,4,10,35)
Strength and stability of BNSC (10,11,13,21)			+	35,27,18,2,(9,11,33)	2,10,14,16,19,35,(25,38)	35,2,17,19,(30,20,11)	35,10,1,(2,19,26,20,11)
Durability of the BNSC (14,27,29,30,31)				+	35,2,19,32,10,22,(24,21,11,33)	27,40,2,(3,15,32,35,25,23,11,31,33)	2,1,10,11,35,(25,31)
Energy (17,18,19,20,22)					+	35,2,19,(15,26,31)	28,2,16,17,26,7
Ease of use and user satisfaction (33,35,37,38)						+	1,13,26,(13,28,12,5,7,11,31)
Builder convenience (32,34,36)							+

Recommended Inventive principle's numbers from Archi-Triz to solve the contradiction	Title of each recommended principle	Description of each principle	Our solution (OS) based on each principle
Principle 29	Pneumatics and hydraulics	It recommends using parts that have gas or liquid inside them rather than solid components.	1-design a two-layer wall with a pneumatic system inside it. 2- To change the diameter of the wall, air jacks or airbags can be installed. 3- This system will reduce the wall's diameter faster , and as a result speed and time will not be lost.
Principle 10	Preliminary Action	In principle number ten, "preliminary anti-action, prior counter-action" refers to changing an object (either fully or partially) prior to its changes being required. Organize the objects beforehand so they can be delivered to the most convenient location and used quickly. Prepare the objects beforehand in order to be able to place them into action at the most convenient location and without losing time in delivery.	1- Two-layer walls can be designed and constructed with prefabricated parts to reduce installation time. 2- It is possible to design some keys. By pressing the appropriate key, one of the walls can be moved, and the number of rooms in the building plan can be reduced or increased. 3-It can inspire designers to consider creating a manual or even automatic key with sensors to move the wall at a specific time and to a specific location.
Principle 8	Anti-weight	It suggests merging an object's weight with others that provide lift. Therefore, an object's weight can be controlled by its environment (for example, using aerodynamic, hydrodynamic, and buoyancy forces).	It means that the weight of the object can be compensated with hydrodynamic or aerodynamic forces . In other words, a wall Can be designed by hydrodynamic or aerodynamic forces which can go up and down in Z direction (figure 3). So, the wall can be moved faster by this solution.
Principle 15	Dynamics	1- Dynamicity refers to the idea that an object's components should be changeable or dynamic . 2- So, these components can become optimal or recommend finding optimal operating conditions . 3-Furthermore, it recommends the division of an object into parts that can move relative to each other . 4- Additionally, this inventive principle recommends that a rigid or inflexible object (or process) be made movable or adaptable .	The wall specifications can have dynamicity and adaptability to the conditions of the occupants. Also, the wall could be designed to be automatically adjusted for optimal operation at each step of movement . Also, it is inspiring for a designer to develop a home that can have both a manual wall movement control system and an automated wall movement control system controlled by computer systems with sensors installed in each bedroom and hallway depending on whether the occupants are present during the day or at night in which area of the apartment. Therefore, the apartment can have a larger hall area during the day by moving walls for allowing one bedroom to be eliminated by a manual or automatic time setting system for optimal space utilization .

Figure 7.4 The first phase is the creativity process
Taken from Hassanijajini et al. (2024)

In this scenario, there are 12 system characteristics, such as wall materials, operating mechanisms, connector types, insulation materials, structural frame materials, decorative options, maintenance management systems, folding wall storage locations, finish surface types, movable wall door mechanisms, cost-efficient production and logistics, and product design approaches. For example, wall materials include different options: wood walls which ranked 1 and composite walls ranked 2. So, wood wall has been selected as wall material. Using QFD, one option is selected by evaluating and ranking available choices, as illustrated in Figure 7.7. This process could be applied to all system characteristics of the product to identify the better options.

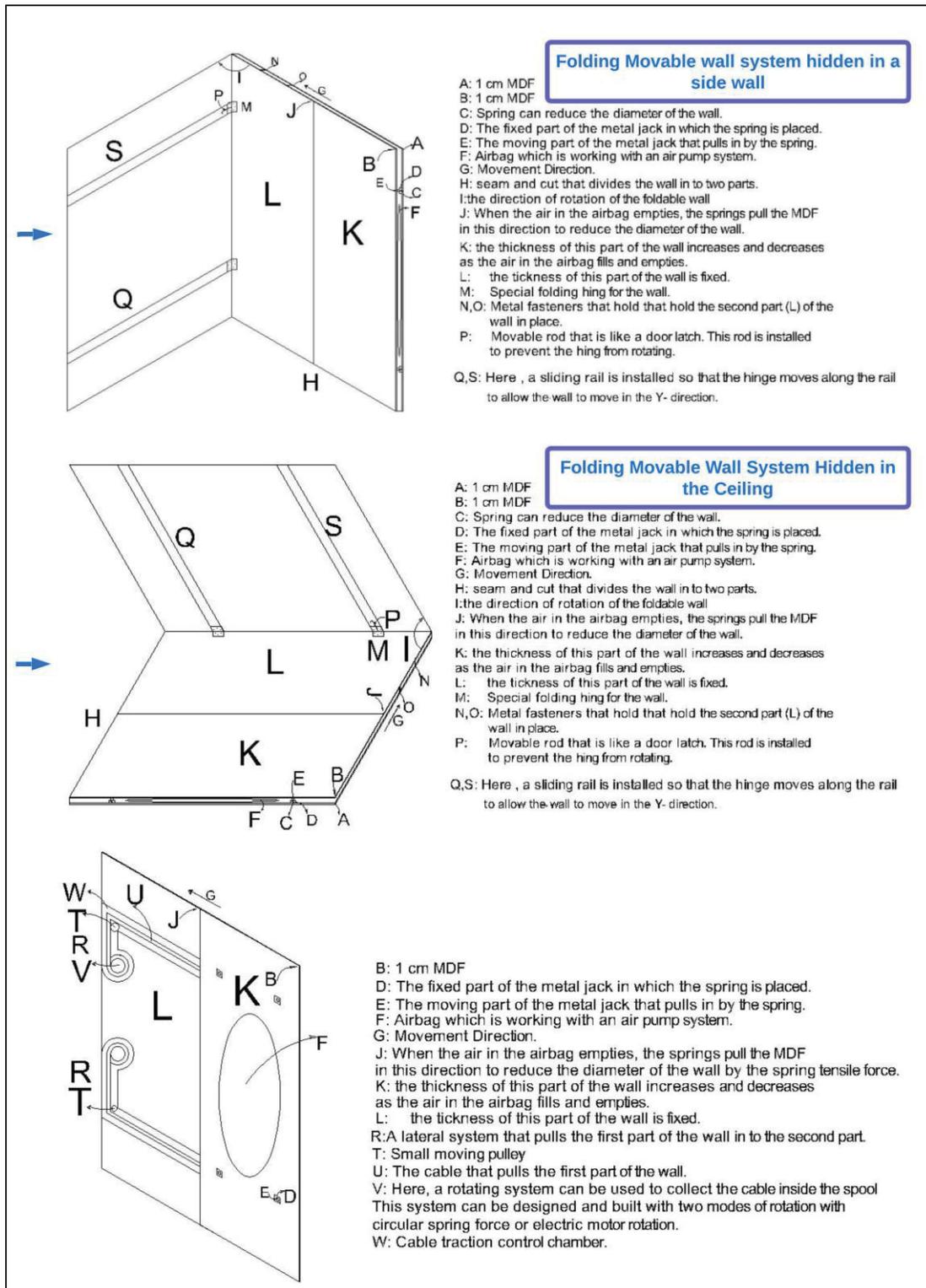


Figure 7.5 Moveable walls
 Taken from Hassanijajini et al. (2024).

Figure 7.5 illustrates the details of two movable wall designs developed using Archi-TRIZ.

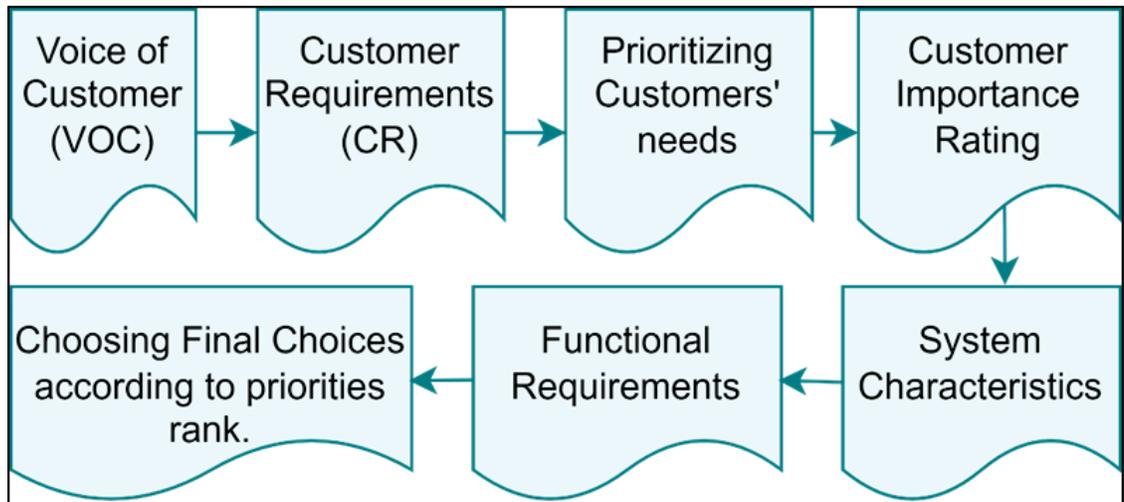


Figure 7.6 The second phase involves creating the QFD matrix steps.

Figure 7.6 illustrates the second phase of the methodology and the steps of getting the voice of the customer to translate it into system characteristics.

Customer importance rating	System characteristics Functional Requirements (How's) → Customer Requirements - (What's) ↓	Wall Material		Operating Mechanisms		Connector Type		Insulation Material		Structural Frame Material		Decorative option	
		Wood Wall	Composite Wall	Manual Mechanism	Electric Mechanism	Screws Connection	Adhesive Connection	Mineral Wool (Rock wool or Slag wool)	Polyurethane Foam (Rigid Panels or Spray foam)	Aluminum Structure	Wooden Structure	High-End Decorative Panels	Attractive different colors
		1: low, 5: high											
5	Cost	1	3	5	2	4	3	4	3	2	4	2	5
4	Safety	3	3	3	4	5	3			4	3		
3	ease of use	2	3	2	5								
2	light weight	1	5	4	3	3	4	3	5	5	3	5	3
4	Attractive design	5	2							4	5	4	5
5	Quiet	4	3	4	3			5	4	3	4		
4	Warranty and support	4	2	4	3	4	3					4	3
2	Environmental Sustainability	5	1	5	3			3	2	3	5		
5	Durability and longevity	4	5	4	5	5	3	5	4	5	4	4	3
Technical importance score		111	104	117	105	87	62	82	69	98	108	72	78
Importance %		9%	9%	10%	9%	7%	5%	7%	6%	8%	9%	6%	7%
Priorities rank		1	2	1	2	1	2	1	2	2	1	2	1

Customer importance rating	System characteristics Functional Requirements (How's) → Customer Requirements - (What's) ↓	Maintenance Management System		Folding Wall Storage Location		Finish surface type		Movable Wall's Door Mechanism		Lost-efficient Production and Logistics		Product Design Approach	
		Automated Preventive Maintenance alerts	Manual Maintenance Request via App	Option 2: Folding Movable Wall System Hidden in the Ceiling	Option 1: Folding Movable Wall System Hidden in a Side Wall	Matte Finish Panels	Glossy Finish Panels	Concealed Sliding Doors	Hinged Doors Embedded in Walls	Overseas Manufacturing and Marine Freight	local production	modular design	not modular design
		1: low, 5: high											
5	Cost	4	3	2	4	4	3	3	4	5	3	5	2
4	Safety	5	4	3	4			5	3	3	4	3	4
3	ease of use	5	4	2	4			5	4				
2	light weight			2	3	5	5			5	3	4	2
4	Attractive design			5	4	4	5	5	4				
5	Quiet			3	4			5	4				
4	Warranty and support	5	4	3	4	4	5	4	3	3	4	4	5
2	Environmental Sustainability												
5	Durability and longevity	5	3	3	4	4	5	5	4			4	5
Technical importance score		100	74	94	126	82	90	136	112	59	53	81	75
Importance %													
Priorities rank		1	2	2	1	2	1	1	2	1	2	1	2

Figure 7.7 QFD Matrix

As illustrated in figure 7.7, If there are n system characteristics, then there are one or more options for each system characteristic to choose among them. At the end of this cycle, one option could be selected for each system characteristic. Sometimes, due to various factors such as limited budget or time constraints, one characteristic could be eliminated in favor of another by selecting the one with the higher score. The designer determines that a folding movable wall system hidden in a side wall (option 1) is preferable to a system hidden in the ceiling

(option 2) for movable walls. This preference is based on the side-wall system (option 1) achieving a technical importance rating of 126 (highlighted by a red line around it), ranking first and indicating greater acceptability among customers. As shown in Figure 7.7 (QFD matrix), the first customer requirement with the highest importance rating of 5 is cost. It is very important to have affordable parts that are buyable by the proposed customers. In the QFD selection process, each system characteristic—such as the operating mechanism's cost—has been considered. For example, a manual mechanism, which is cheaper and has a score of 5, ranks higher than the electronic system, which has a score of 2.

Building Information Modeling (BIM) is a digital process that could be used by engineers, and other experts in the construction industry from the design phase until operation and other stages of the building's life cycle, even up to demolition. BIM is essentially a 3D model of the building. The proposed methodology in this paper, which combines Archi-TRIZ and QFD, could be added to BIM to introduce design options through Archi-TRIZ and gather customer requirements through QFD. This integration provides architects and engineers with more innovative design options by considering customer needs, thereby increasing customer satisfaction.

7.4 Conclusion

In this research, a new mixed methodology using Archi-TRIZ and QFD is presented. For each system characteristic of the production, the customer needs are identified. These customer needs could then be used to improve the design of each system characteristic. For example, there may be 12 system characteristics, each with n options, which are filtered through QFD to produce a product catalog and identify the better options to increase customer satisfaction. This cycle could be repeated by utilizing Archi-TRIZ for any customer needs that were overlooked in the first or second phases, adding more details to the movable wall example. Then, QFD could be applied again to achieve greater customer satisfaction if needed.

7.5 Future work

As part of future work, it is possible to apply methodology including Archi-TRIZ and QFD in a new cycle to expand the details of the movable wall example. This cycle could provide opportunities for adding more inventive solutions and the improvement of design characteristics to better address customer needs and functional requirements.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

CHAPTER 8

HOW TO USE ARCHI-TRIZ MATRIX WITH QFD TO BETTER DESIGN BUILDING NON-STRUCTURAL COMPONENTS

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8.1 Abstract

One of the main challenges in building design is that current approaches often fail to fully address innovation-based designs that meet customers' needs. Previous research introduced the Archi-TRIZ approach and applied it to a movable wall example. A mobile application and website were also developed, featuring inventive examples from various fields, such as civil engineering, structural engineering, architecture, and road construction. These tools provide building designers with creative examples linked to specific inventive principles, inspiring more innovative designs.

This research aims to enhance movable wall systems by adding details and attachment systems to optimize flexible spaces while addressing diverse customer needs. In earlier studies, the Archi-TRIZ approach was applied to develop the Foldable-Wall system, demonstrating its effectiveness in accelerating the design process and offering inventive solutions that improve adaptability and user satisfaction. With QFD, we refined the design further, prioritizing customer requirements and adding detailed features to the movable wall example.

In the next phase, we plan to repeat the design cycle using Archi-TRIZ to introduce additional innovative components and solutions. Then, one option will be selected for each system characteristic based on the highest scores and rankings in QFD to enhance customer satisfaction. This iterative process demonstrates Archi-TRIZ's potential to inspire creative

solutions for non-structural components, ultimately enhancing design quality and customer satisfaction.

8.2 Introduction

8.2.1 TRIZ

The design of building systems, particularly those that emphasize flexibility and adaptability, remains a significant challenge in architecture and engineering. Traditional design methodologies often fall short in addressing the need for innovative, customer-driven solutions. TRIZ (a Russian acronym for “Theory of Inventive Problem Solving”) is a methodology that has been introduced by Altshuller (Renev & Chechurin, 2016). The core idea of TRIZ is that enhancing one aspect of a design often leads to the decline of another. To overcome this challenge, TRIZ provides inventive principles (IPs) that guide designers in finding creative solutions. By studying these principles and relevant examples, designers could develop innovative ideas that improve one feature without worsening another, leading to optimized engineering processes (Ekmekci & Nebati, 2019; Renev & Chechurin, 2016).

Altshuller by analysing 40,000 inventions introduced 40 IPs (Hassanijajini & Gardoni, 2022; Kulatunga et al., 2006) that has been shown in previous paper. The original TRIZ has 39 improving and 39 worsening features. By considering 3 or 4 IPs that has been introducing by TRIZ, the designers could be inspired to solve chosen contradiction by introducing inventive solutions based on these IPs.

TRIZ is applicable in many fields (such as computers, IT, software, electronics, mechanical engineering, automotive industry, etc.) but its direct application in construction industry is difficult (Blayse & Manley, 2004; Cavallucci, 2009; Dale, 2007; Hassanijajini & Gardoni, 2022; Kulatunga et al., 2006; Ozorhon et al., 2010; Renev & Chechurin, 2016). So, Archi-TRIZ has been introduced to fulfill this gap in the previous research (Hassanijajini et al., 2024).

8.2.2 Archi-TRIZ

The Archi-TRIZ approach, an adaptation of the well-established TRIZ methodology for architecture and design, has emerged as a promising tool to bridge this gap. It has been

successfully applied to examples, such as movable wall systems, where it has demonstrated its potential in fostering creativity and improving design outcomes (Hassanijajini et al., 2024).

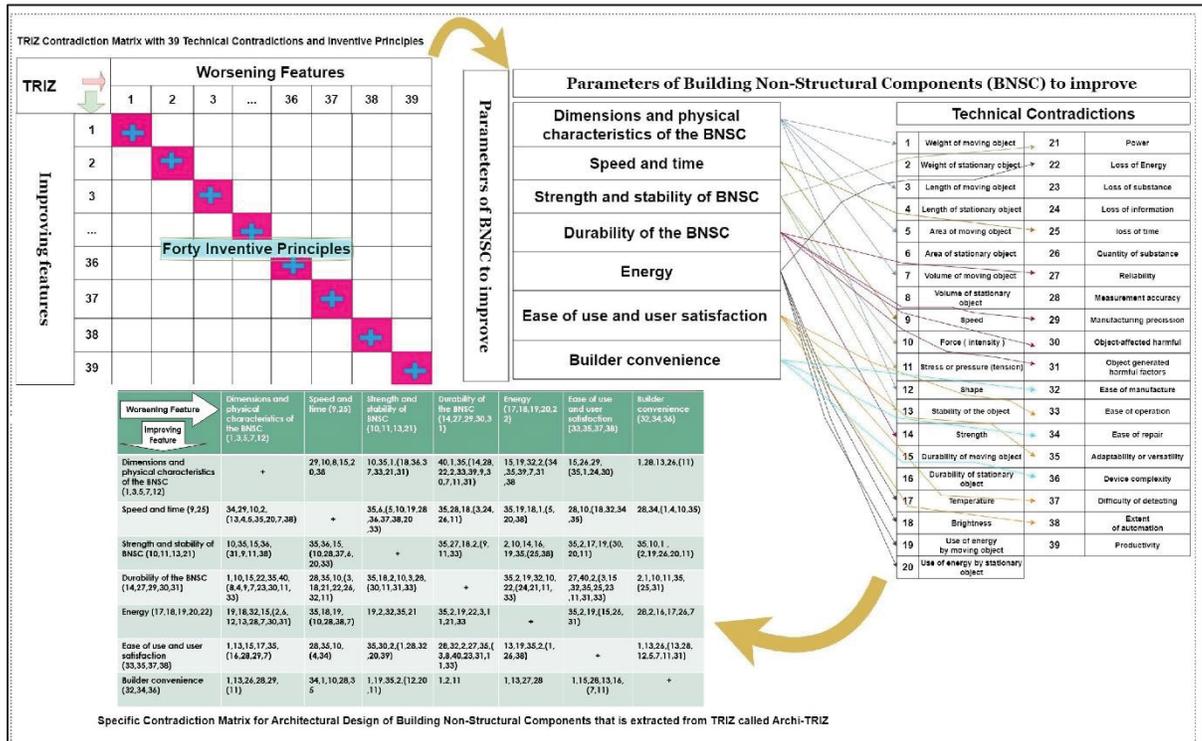


Figure 8.1 Steps of creating Archi-TRIZ Taken from Hassanijajini et al. (2024)

This matrix was derived from the original TRIZ contradiction matrix using a seven-step process within our previous project. A summary matrix was initially created through these steps, but due to space constraints, only one step is presented here. Table 8.1 offers further clarification, while Figure 8.1 outlines the steps involved in developing Archi-TRIZ. Figure 8.1 shows how 39 technical contradictions of TRIZ are combined to find out 7 improving and worsening features for the Archi-TRIZ. For example, technical contradiction number 9 in TRIZ, "Speed," is connected to technical contradiction number 25, "Loss of Time," in the original TRIZ. This relationship indicates that lower speed results in greater time loss, while increasing speed saves time and accelerates the process. Due to this connection, "Speed" and "Time" have been combined as the second technical contradiction in the Archi-TRIZ matrix. Dimensions and physical characteristics of the Building nonstructural components (BNSC)

that is the first technical contradiction in the Archi-TRIZ is also the combination of technical contradiction number 1,3,5,7 and 12 of the original TRIZ which are weight of moving object, length of moving object, area of moving object, volume of moving object and shape of moving object. By this trend, all the other technical features of Archi-TRIZ such as Strength and stability of BNSC, durability of the BNSC, energy, ease of use and user satisfaction, builder convenience have been introduced (table 8.1).

Table 8.1 Step one of preparing Archi-TRIZ
Taken from Hassaniyajini et al. (2024)

 	Dimensions and physical characteristics of the BNSC (1,3,5,7,12)	Speed and time (9,25)	Strength and stability of BNSC (10,11,13,21)	Durability of the BNSC (14,27,29,30,31)	Energy (17,18,19,20,22)	Ease of use and user satisfaction (33,35,37,38)	Builder convenience (32,34,36)
Dimensions and physical characteristics of the Building non-structural component (BNSC) (1,3,5,7,12)	+	2, 8, 15, 38 13, 4, 8 29, 30, 4, 34 29, 4, 38, 34 35, 15, 34, 18 = 34,29,38 10, 35, 20, 28 15, 2, 29 26, 4 2, 6, 34, 10 14, 10, 34, 17 = 10,34,20	8,10,18,37,10,36, 37, 40,1, 35, 19, 39,12, 36, 18, 31 = 10,18,36,37 17, 10, 4,1, 8, 35, 1, 8, 15, 34,1, 35 = 1,8,35 19, 30, 35, 2 11, 2, 13, 39 19, 10, 32, 18 = 10,19,2 15, 35, 36, 37 6, 35, 36, 37 28, 10, 1, 39 35, 6, 13, 18 = 35,36,37 35, 10, 37, 40 34, 15, 10, 14 33, 1, 18, 4 32, 35, 27, 31 = 10,35,33,31	28, 27, 18, 40,8, 35, 29, 34,3, 15, 40, 14,9, 14, 15, 7,30, 14, 10, 40 = 14,40,15,7 1, 3, 11, 27,10, 14, 29, 40 29, 9,14, 1, 40, 11,10, 40, 16 = 40,14,29,11,9 28, 35, 26, 18,10, 28, 29, 37 2, 32, 25, 28, 2, 16,32, 30, 40 = 28,32 22, 21, 18, 27 1, 15, 17, 24 22, 33, 28, 1 22, 21, 27, 35 22, 1, 2, 35 = 22,1,21,27,35,33 22, 35, 31, 39,17, 15,17, 2, 18, 39,17, 2, 40, 1,35, 1 = 17,1,2,35,39,(30,31)	6,29,4,38,10,15, 19,2,15,16,34, 39, 10, 18,22, 14, 19, 32 = 10,15,19,38 19, 1, 32,32,15, 32, 19, 13,2, 13, 10,13, 15, 32 = 32,13,19 35, 12, 34, 31,8, 35,24,19,32,35,2 , 6, 34, 14 = 35,34 6, 2, 34, 19,7, 2, 35, 39,15, 17, 30, 26,7, 15, 13, 16,14 = 2,7,15,39	35, 3,2,24,15,29, 35, 4,15, 17, 13, 16,15,13,30,12,3 2, 15, 26 = 15,13,35 29,5,15,8,14,15,1 ,16,15,30,15,29,1 , 15, 29 = 15,29,1 28, 29, 26,32,35, 1,26,24,2,36,26,1 8,29,26,4,15,13, 39 = 26,29 26, 35 18, 19,17, 24, 26, 16,14,30, 28, 23,35, 34,16, 24,15, 1, 32 = 26,35,24,(30,14)	27, 28, 1, 36,1, 29, 17,13,1,26, 24,29, 1, 40,1, 32, 17,28 = 1,28 2, 27, 28, 11,1, 28,10,15,13,10 , 1,10,2, 13, 1 = 1,10,2,28,13,11 26, 30, 36, 34 1, 19,26,24,14, 1,13,26, 1,16, 29, 1, 28 = 1,26

The next step is gathering IPs in table 8.1 that has come out of original TRIZ. The most repetitive IPs have been chosen and ranked in table 8.2. In table 8.1, For instance, under the worsening feature speed and time there are several numbers. The question is that, where was these answers? How these IPs have been gathered? If you go to the original TRIZ and see the intersection of improving feature number 1 (weight of moving object) and worsening feature number 9 (speed), the TRIZ will state that Inventive principle number (IPN) 2,8,15,38 could persuade the designer to find an innovative solution to solve the contradiction. So, the IPN 2,8,15,38 has been written in table 8.1 under the speed and time (9,25) column as first line. Also, if you go to the original TRIZ and see the intersection of improving feature number 3 (length of moving object) and worsening feature number 9 (speed), the TRIZ will state that IPN 13,4,8 could persuade the designer to find an innovative solution to solve the

contradiction. So, the IPN 13,4,8 has been written in table 8.1 under the speed and time (9,25) column as the second line.

The line three has been come out of intersection between improving feature number 5 (area of moving object) and worsening feature number 9 (speed) of original TRIZ. This trend has been done several times. After that, all the data has been gathered in table 8.2. The seven tables like table 8.1 for each improving features has been produced by this trend. The most repetitive principles have been ranked and chosen based on repetition and highest creativity in Archi-TRIZ (table 8.2).

Table 8.2 Archi-TRIZ for Enhancing Innovation in the Design of BNSC
Taken from Hassanijajini et al. (2024)

	Dimensions and physical characteristics of the BNSC (1,3,5,7,12)	Speed and time (9,25)	Strength and stability of BNSC (10,11,13,21)	Durability of the BNSC (14,27,29,30,31)	Energy (17,18,19,20,22)	Ease of use and user satisfaction (33,35,37,38)	Builder convenience (32,34,36)
Dimensions and physical characteristics of the BNSC (1,3,5,7,12)	+	29,10,8,15,20,38	10,35,1,(18,36,37,33,21,31)	40,1,35,(14,28,22,2,33,39,9,30,7,11,31)	15,19,32,2,(34,35,39,7,31,38)	15,26,29,(35,1,24,30)	1,28,13,26,(11)
Speed and time (9,25)	34,29,10,2,(13,4,5,35,20,7,38)	+	35,6,(5,10,19,28,36,37,38,20,33)	35,28,18,(3,24,26,11)	35,19,18,1,(5,20,38)	28,10,(18,32,34,35)	28,34,(1,4,10,35)
Strength and stability of BNSC (10,11,13,21)	10,35,15,36,(31,9,11,38)	35,36,15,(10,28,37,6,20,33)	+	35,27,18,2,(9,11,33)	2,10,14,16,19,35,(25,38)	35,2,17,19,(30,20,11)	35,10,1,(2,19,26,20,11)
Durability of the BNSC (14,27,29,30,31)	1,10,15,22,35,40,(8,4,9,7,23,30,11,33)	28,35,10,(3,18,21,22,26,32,11)	35,18,2,10,3,28,(30,11,31,33)	+	35,2,19,32,10,22,(24,21,11,33)	27,40,2,(3,15,32,35,25,23,11,31,33)	2,1,10,11,35,(25,31)
Energy (17,18,19,20,22)	19,18,32,15,(2,6,12,13,28,7,30,31)	35,18,19,(10,28,38,7)	19,2,32,35,21	35,2,19,22,3,1,21,33	+	35,2,19,(15,26,31)	28,2,16,17,26,7
Ease of use and user satisfaction (33,35,37,38)	1,13,15,17,35,(16,28,29,7)	28,35,10,(4,34)	35,30,2,(1,28,32,20,39)	28,32,2,27,35,(3,8,40,23,31,1,1,33)	13,19,35,2,(1,26,38)	+	1,13,26,(13,28,12,5,7,11,31)
Builder convenience (32,34,36)	1,13,26,28,29,(11)	34,1,10,28,35	1,19,35,2,(12,20,11)	1,2,11	1,13,27,28	1,15,28,13,16,(7,11)	+

The limitation of Archi-TRIZ is that it could not consider customer needs, to solve this problem, Quality Function Deployment (QFD) could be combined with Archi-TRIZ. QFD not only helped us to choose better option between available options that come out of Archi-TRIZ but also helped us to add more details to the moveable wall example. In this way, the result of Archi-TRIZ could be improved and results could satisfy both engineer and customer.

8.2.3 Application of Archi-TRIZ Principles in Movable Wall Design

In this section, the aim is enhancement the improving feature, "dimension and physical characteristics of the BNSC," without worsening the "speed and time" feature for designing movable wall. So, Archi-TRIZ recommends applying principles 9, 10, 8, 15, 20, and 38. The top-ranked principles (9, 10, 8, and 15) was used to develop innovative solutions which explained below.

Principle 29: Pneumatics and Hydraulics

Concept. This principle suggests utilizing components containing gas or liquid instead of solid materials.

Implementation.

1. Design a two-layer wall incorporating a pneumatic system.
2. Install air jacks or airbags to modify the wall's diameter dynamically.
3. This system facilitates rapid wall resizing, enhancing efficiency without time delays.

Principle 10: Preliminary Action

Concept. Principle 10, "Preliminary Anti-Action" or "Prior Counter-Action," involves modifying an object—either fully or partially—before the change is actually needed. This approach ensures that objects are prearranged in advance, allowing them to be deployed quickly at the most suitable location. By preparing objects beforehand, they could be put into action efficiently without delays in delivery or unnecessary time loss.

Implementation.

1. Construct two-layer walls using prefabricated components to minimize installation time.
2. Introduce control keys that allow walls to move, enabling flexible space allocation.
3. Develop a manual or automated key system with sensors to reposition walls at specific times and locations efficiently.

Principle 8: Anti-weight

Concept. This principle advocates reducing an object's weight by leveraging external lift forces, such as aerodynamic, hydrodynamic, or buoyancy effects.

Implementation.

1. Design walls that utilize hydrodynamic or aerodynamic forces to facilitate movement.
2. Implement a system enabling vertical (Z-axis) wall movement, allowing walls to rise and lower as needed, ensuring faster adjustments.

Principle 15: Dynamics

Concept. Dynamicity refers to ensuring that an object's components remain adaptable, capable of movement, and optimized for varying conditions.

Implementation.

1. Design walls with adaptability, allowing them to change in response to occupant needs.
2. Implement an automated control system for walls, enabling them to adjust positioning based on user activity.
3. Incorporate sensors in bedrooms and hallways to detect occupancy, automatically modifying the space configuration.
4. Utilize movable walls to create larger hall areas during the day and adjust room layouts dynamically for optimal space utilization.

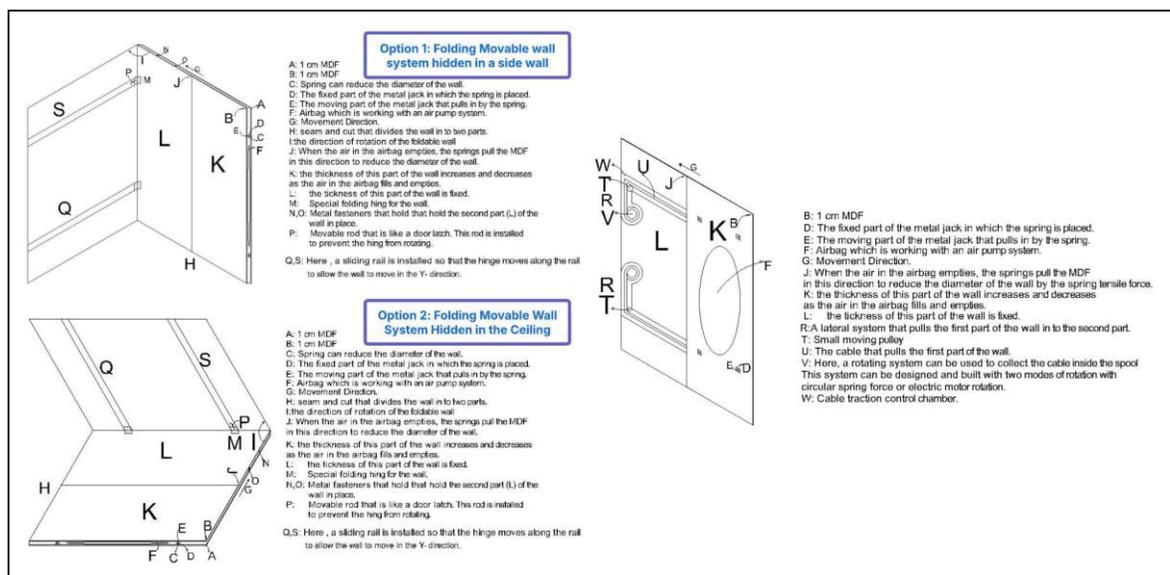


Figure 8.2 Two options of movable walls
 Taken from Hassanijajini et al. (2024)

8.2.4 QFD

The QFD methodology concept was defined in Japan for first time to imply customers needs in design products in order to increase the quality of the productions (Akao, 1997; Sarkar & Panchal, 2017). QFD helps designers team to decrease the possibility of wasting costs and time by scoring, ranking and choosing the more important factors (Ahmed & Amagoh, 2010). TRIZ with QFD were combined in various studies to enhance innovation-based products by considering customer needs (Caligiana et al., 2017; Kim et al., 2022; Naveiro & Oliveira, 2018; W. Yang et al., 2021). However, this combination was limitedly used in building design (Molina & Desai, 2023; Oh et al., 2017). Also, searching the Archi-TRIZ contradiction matrix with QFD yields no results.

System characteristics		Wall Material		Operating Mechanisms		Connector Type		Insulation Material		Structural Frame Material		Decorative option		Maintenance Management System		Folding Wall Storage Location		Finish surface type		Movable Wall's Door Mechanism		Cost-Efficient Production and Logistics		Product Design Approach	
Functional Requirements (How's) →	Customer Requirements - (What's) ↓	Wood Wall	Composite Wall	Manual Mechanism	Electric Mechanism	Screw Connection	Adhesive Connection	Mineral wool (Rock wool or Slag wool)	Polyurethane Foam (Rigid Panels or Spray foam)	Aluminum Structure	Wooden Structure	High-End Decorative Panels	Attractive different colors	Automated Preventive Maintenance alerts	Manual Maintenance Request via App	Option 2: Folding Movable Wall System Hidden in the Ceiling	Option 1: Folding Movable Wall System Hidden in a Side Wall	Matte Finish Panels	Glossy Finish Panels	Concealed Sliding Doors	Hinged Doors Embedded in Walls	Overseas Manufacturing and Marine Freight	local production	modular design	not modular design
1: low, 5: high	Customer importance rating																								
5	Cost	1	3	5	2	4	3	4	3	2	4	2	5	4	3	2	4	4	3	3	4	5	3	5	2
4	Safety	3	3	3	4	5	3			4	3			5	4	3	4			5	3	3	4	3	4
3	ease of use	2	3	2	5									5	4	2	4			5	4				
2	light weight	1	5	4	3	3	4	3	5	5	3	5	3			2	3	5	5			5	3	4	2
4	Attractive design	5	2							4	5	4	5			5	4	4	5	5	4				
5	Quiet	4	3	4	3			5	4	3	4					3	4			5	4				
4	Warranty and support	4	2	4	3	4	3					4	3	5	4	3	4	4	5	4	3	3	4	4	5
2	Environmental Sustainability	5	1	5	3			3	2	3	5														
5	Durability and longevity	4	5	4	5	5	3	5	4	5	4	4	3	5	3	3	4	4	5	5	4			4	5
	Technical importance score	111	104	117	105	87	62	82	69	98	108	72	78	100	74	94	126	82	90	136	112	99	53	81	75
	Importance %	9%	9%	10%	9%	7%	5%	7%	6%	8%	9%	6%	7%	9%	6%	8%	11%	7%	8%	12%	10%	9%	5%	7%	6%
	Priorities rank	1	2	1	2	1	2	1	2	2	1	2	1	1	2	2	1	2	1	1	2	1	2	1	2

Figure 8.3 QFD Matrix

In figure 8.3, First the Voice of Customer (VOC) such as cost, safety, ease of use, light weight, attractive design, quiet, warranty, environmental sustainability and durability are gathered and written as customer requirement (What's) in the QFD matrix. Then customer importance rating has been allocated to each customer requirements. After that, system characteristics including wall material, operating mechanisms, connector type, insulation material, structural frame material, decorative options, maintenance management system, folding wall storage location, finish surface type, movable walls door mechanism, cost-efficient production and logistics, and product design approach has been written on top of the QFD matrix. There are two options in each systems characteristic which has scores. For example, wood wall safety score (3) and

its important rate (4) etc. And the final score of technical importance score is the sum of all these multiples. The equation is written in the following.

$$[(5 \times 1) + (4 \times 3) + (3 \times 2) + (2 \times 1) + (4 \times 5) + (5 \times 4) + (4 \times 4) + (2 \times 5) + (5 \times 4)] = 111$$

All technical importance score in QFD matrix calculated like above mentioned formula. And then first ranked items have been chosen as a final option. For instance, wood wall technical importance score, which is 111, is greater than composit wall technical importance score, which is 104, it means wood wall ranked 1. As a result, the wood wall has been chosen as a final wall material.

In our previous study, two options were introduced for the storage location of the folding wall as part of Archi-TRIZ's movable wall example, highlighted with a red outline. Option one, where the folding movable wall system is hidden within a side wall, received a score of 126, ranking first. In comparison, option two scored 94 and ranked second. As a result, option one was selected as the preferred choice.

For improving the result, these two phases could be repeated, so the methodology of this research is explained in the following section.

8.3 Methodology

This section describes the methodology of our research. As it is mentioned in above section Archi-TRIZ could be used to enhance innovation in design. Also, QFD could be used to consider customers need and make the results of Archi-TRIZ more user friendly. So, these opportunity of Archi-TRIZ and QFD inspire us to use these two steps again to check how it impacts on results. The first step is using Archi-TRIZ to find the results, then QFD is used in the second step to combine end users' needs and preferences with the results of the previous step. Then this loop could be used to improve the results of the second step by using Archi-TRIZ and QFD in step three and four.

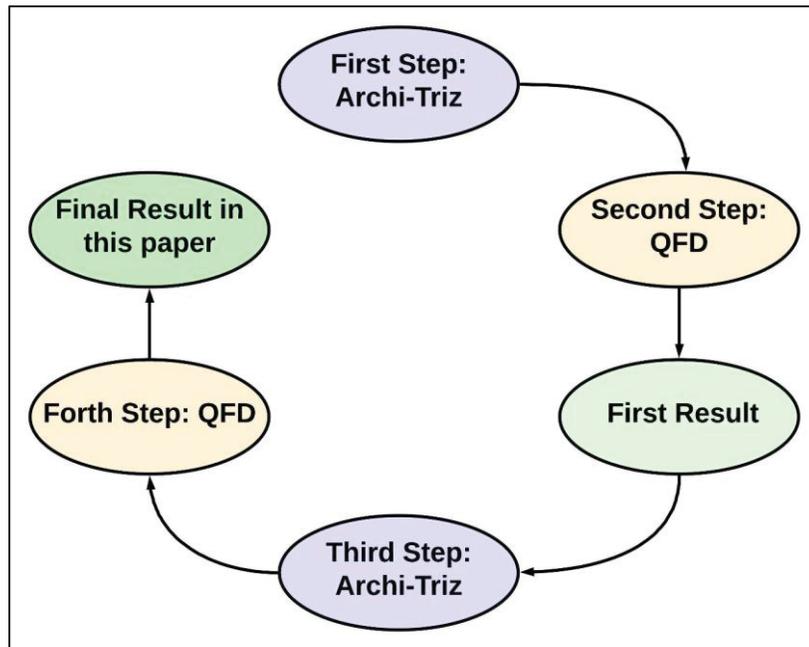


Figure 8.4 Methodology road map

Previous study builds upon previous applications of the Archi-TRIZ methodology, particularly in the development of the Foldable-Wall system, which has proven effective in accelerating the design process while improving adaptability and user satisfaction. By incorporating customer requirements through QFD, we refine the design to ensure that it meets the needs of users. The design cycle planned for the next phase of this research aims to introduce even more innovative components, further enhancing the system's functionality and overall design quality.

8.4 Results and Discussion

8.4.1 Application of Archi-TRIZ Principles for the second Time

It is possible to use Archi-TRIZ as illustrated in the tablet (figure 8.5) for second time. The previous research explores the integration of Archi-TRIZ with QFD to optimize movable wall systems by introducing innovative attachment methods and enhancing flexible spaces. In previous research, a mobile application and website has been developed, featuring inventive

examples from diverse fields, including civil engineering, structural engineering, and architecture, further supports this effort by providing designers with a broad range of creative, inventive examples for each IP. These tools not only inspire new design possibilities but also facilitate the application of these IPs to real-world building challenges.

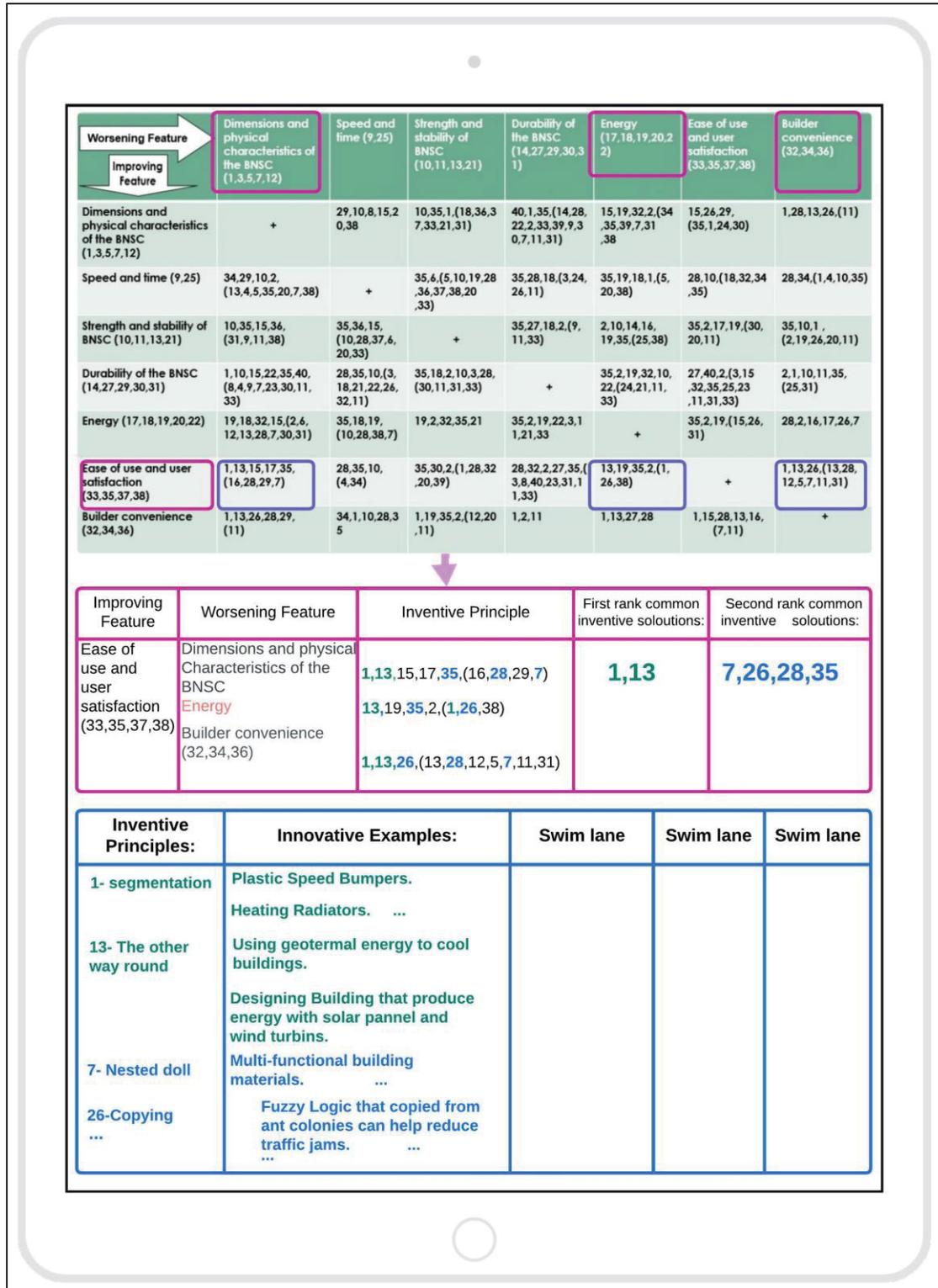


Figure 8.5 the Archi-TRIZ and its examples in building design and construction fields could be in a mobile app or website.

In second cycle of the methodology, designers could design some additional innovative features for the moveable wall's example. If the designers want to improve "ease of use and user satisfaction", the worsening feature is "dimension and physical characteristics of the building non-structural components (BNSC)". The Archi-TRIZ illustrate that IPN 1,13,15,17,35,16,28,29,7 could give opinion to the designer to eliminate this contradiction (figure 8.5). It means by using one of these principles the designer could introduce an inventive solution to solve contradiction between improving feature "improving ease of use and user satisfaction" without worsening "the dimension and physical characteristics of the BNSC".

The possible solution based on each IP could be like below:

Segmentation is IPN1 which is referring to examples such as puzzle, multi-piece walls, etc. In this scenario, origami shape walls could be one of the solutions (figure 8.6). So, it is possible to use two layers of the wall by considering origami shape.



Figure 8.6 origami walls based on
IPN1 segmentation
Taken from Melnyk (2022)

In figure 8.5, first rank common IPNs are IPN1 and IPN13. So, by utilising solutions based on INP1, it is possible to improve ease of use and user satisfaction without worsening builder convenience. It means, segmentation could inspire to design a kind of a prefabricated wall

structure with small pieces that is foldable, and these pieces could be assembled on site. It is noteworthy to state that all the principles that has been introduced by Archi-TRIZ could give in mind different inventive solutions but IPN 1, 13 are solving all three contradiction together. Since they are first rank common inventive solutions for all three worsening features, including ease of use and user satisfaction, energy and builder convenience. After utilising first rank solutions, it is time to try second rank common inventive solutions including IPN 7,26,28,35 to find more options that could cover all three worsening features as second or third inventive solutions like origami walls or etc. Then all these solutions with their options could be in a QFD matrix to allow designers to choose the better option based on customer's needs.

The second IP that has been distinguish as “first rank common inventive solutions”, according to figure 8.5 is IPN13 (the other way round). In figure 8.5 under the innovative examples' column, IPN 13 recommend designing building produce energy. According this IPN, it is possible to introduce manual system that equipped with some tools like exercise bicycle that not only help to move the moveable wall but also producing energy. To avoid complexity in electrical equipment to save the energy, it is possible to design mechanical system that is working with the weight. In this scenario, the heavy component hidden between 2 layers of the wall could go 2.8 meter upper than floor of the apartment and then come down slowly and for example produce electrical energy to be used when ever needed by this mechanical system. By considering and thinking on All of the IPN's, it is possible to find out several inventive solutions and add more details to our moveable wall example.

8.4.2 IPs Suggested by Archi-TRIZ

This section present explanation, examples, and application of each IP that has been come out of Archi-TRIZ to solve three contradictions including dimension and physical characteristic of the “BNSC”, energy”, “builder convenience” with “ease of use and user satisfaction”. As it is mentioned in the previous section, the IPN 1 and 13 has been repeated in all three above mentioned contradictions. In figure 8.5, IP 1,13 has been ranked as the first most repetitive principles showed in green colour. Also, IP 7,26,28,35 has been ranked as the second repetitive group of IPs to solve all three contradictions highlighted in blue colour.

8.4.2.1 Segmentation (IP 1)

This principle promotes dividing an object into smaller parts or increasing segmentation to enhance functionality (Genrich Altshuller et al., 2020; Retseptor, 2003). Examples mentioned in the following:

- Shutter curtains
- Plastic speed bumps
- Heating radiators
- Prefabricated metal structures (e.g., factory sheds) assembled on-site for improved quality (Paudel et al., 2016).
- Prefabricated bridges (smaller parts for easier transport and assembly, reducing costs and time) (Hällmark et al., 2012).

Finally, our solution (OS) is dividing the wall into attachable smaller parts improves builder convenience, reduces energy consumption for movement, and enhances user satisfaction.

8.4.2.2 The Other Way Round (IP 13)

The "Other Way Round" principle, also known as inversion or upside-down, inspires designers to reverse actions, such as moving fixed parts or fixing movable parts to solve problems (Genrich Altshuller et al., 2020).

In building design, this principle has led to sustainable innovations, including the use of geothermal energy for cooling and the development of energy-generating buildings equipped with solar panels, wind turbines, and geothermal systems (Breesch et al., 2005; Maerefat & Haghighi, 2010; Oropeza-Perez & Østergaard, 2018).

This principle also suggests the idea that, instead of consuming the building's electricity and increasing utility costs, an innovative approach could be used to generate energy and reduce the electricity bill. Since the manual mechanism for the operating system of the movable wall in the previous cycle of the QFD matrix (Figure 8.3) received the highest rank with a technical importance score of 117, compared to the electrical mechanism, which was ranked second with

a score of 105, we are exploring a creative manual solution to align with this priority, rather than using solar panels or wind turbines, which are electrical systems. Our innovative solution, based on this IP, is to use a counterweight system instead of relying entirely on an electric or manual system to overcome gravity for lifting the movable wall. The counterweight is placed between two fixed wall layers adjacent to the movable wall. This counterweight is slightly lighter than the movable wall, allowing it to rise as the wall lowers, storing energy. The stored energy could then be used to assist the next movement of the wall. In this way, instead of being hindered by gravity, we leverage it to lift or move the wall.

But what if the wall folds sideways? Would this system still work? The answer is yes. A multi-functional exercise machine or stationary bike could be integrated beside the fixed wall. Household members could use it for exercise, such as cycling or strengthening their arms, shoulders, or legs. This fitness device, connected via cables and pulleys, could help lift the counterweight. A mechanical locking system could hold the counterweight at a specific height, releasing it when needed to provide the necessary energy for moving the wall.

Instead of being a challenge or energy-consuming factor, gravity becomes beneficial in my proposed system. With this innovative solution, I harness gravitational energy to power the movement of the wall. Thus, this IP effectively influences designers to incorporate such creative solutions into their designs.

8.4.2.3 Nested Doll (IP 7)

The Nested Doll principle emphasizes breaking down complex systems into smaller, interconnected components to achieve flexibility, adaptability, and efficiency. This principle could enhance sustainability by simplifying maintenance and upgrades, reducing the need for replacements or disposals. In the context of building design, multi-functional materials that combine layers for insulation, structural support, and aesthetics offer customized solutions. Similarly, nesting roofs that fit within one another provide added insulation and protection, leading to cost savings and improved durability.

Movable wall systems could be adopted by this principle, where wall components nest from the smallest to the largest, fitting together to minimize space when stored. Three potential designs could be developed:

1. *Horizontal Movement.* The wall moves horizontally to the left or right, sliding into adjacent walls when not in use.
2. *Vertical Movement.* The wall extends from top to bottom, storing back into the ceiling when not needed.
3. *Upward Movement.* The wall rises from the floor to create a partition, storing back into the floor when not required.

By selecting the most appropriate design through QFD's second cycle, based on customer preferences and scoring, we ensure that the final solution meets user expectations while offering a flexible, efficient system.

8.4.2.4 Copying (IP 26)

The first thing that comes to mind with this principle is copying from nature. For example, by replicating the ant colony algorithm and fuzzy logic, a movable wall could be designed to operate using a set of sensors and AI algorithms. It could detect room occupancy and recognize user movement patterns to reposition the walls based on real-time data. In high-traffic or crowded spaces, the system could create more open areas by retracting walls, and in quieter moments, it could expand to provide more division between areas.

The second example involves biomimicry-inspired ideas for a movable wall system, based on copying from nature. The Beehive Structure (Honeycomb Design) could inspire designers to consider beehives' hexagonal structure, which maximizes strength while minimizing material use. The application of this idea in movable walls could involve using a lightweight honeycomb core for better sound insulation, strength, and weight reduction, making them easier to retract and reposition.

8.4.2.5 Mechanics Substitution (IP 28)

This principle recommends replacing mechanical elements in a system with optical, sound, magnetic, or electromagnetic elements or olfactory sensors to improve functionality.

Piezoelectric materials have been widely used in civil engineering applications, particularly in building dynamics and road construction. For example, a piezoelectric friction damper (PFD) has been developed as an alternative to mechanical dampers for absorbing dynamic forces. In addition to mitigating vibrations, PFDs generate electrical energy, enhancing efficiency (KITAGAWA et al., 2004). Similarly, pavement energy harvesting utilizes piezoelectric materials to convert mechanical energy from vehicles into electricity, offering a dual-purpose solution for both energy production and vibration mitigation (Adachi et al., 2004; Aydin & Çelebi, 2023; Benjeddou, 2000).

For soil stabilization, elastic geogrids could replace conventional retaining walls or piling techniques. These geogrids reinforce soil structures while reducing excavation, material usage, and labor costs, effectively stabilizing hillsides and slopes (Azadegan & Pourebrahim, 2010). Likewise, biodegradable erosion control blankets made from natural fibers could replace traditional erosion control techniques, providing temporary soil protection while naturally degrading over time, contributing to sustainability (Gyasi-Agyei, 2004).

Application of Mechanics Substitution in Movable Wall Systems.

Building on this principle, our proposed movable wall system incorporates the following innovations:

Replacing Mechanical Rollers with Magnetic Levitation (Maglev). Instead of conventional wheels or rails, movable walls could float on a magnetic track. This approach ensures silent, smooth, and frictionless movement while reducing wear and maintenance requirements.

Substituting Mechanical Locks with Electromagnetic Locks. Traditional latches or bolts could be replaced with electromagnetic locks that automatically engage or disengage through motion sensors, biometrics, or remote control, improving security and ease of use.

8.4.3 Application of QFD for the Second Time

Customer importance rating 1: low, 5: high	System characteristics	Wall Material		Operating Mechanisms				Locking type		Wall Structure	
	Functional Requirements (How's) → Customer Requirements - (What's) ↓	Wood Wall	Honeycomb cardboard hardened with cement water	Manual Mechanism	Manual Mechanism with Multifunctional Exercise Machine	Manual Mechanism with Stationary Bike	Magnetic Levitation for Movable Wall Movement	Mechanical Locks	Electromagnetic Locking System	Space-Saving Nesting Cupboard Wall System Hidden in a Side Wall	Folding Movable Wall System Hidden in a Side Wall
5	Cost	1	5	4	3	3	2	3	2	5	4
4	Safety	3	4	4	4	5	3			4	3
3	ease of use	2	3	2	3	4	5				
2	light weight	1	5	4	2	3	4	4	3	5	3
4	Attractive design	5	5							4	4
5	Quiet	4	5	4	3	4	4	4	4	5	4
4	Warranty and support	4	3	4	3	4	3				
2	Environmental Sustainability	5	4	5	5	5	3	3	2	4	5
5	Durability and longevity	4	3	4	2	4	3	5	4	4	5
	Technical importance score	111	140	116	91	119	98	74	60	120	109
	Importance %	25%	31%	26%	20%	26%	22%	16%	13%	26%	24%
	Priorities rank	2	1	2	4	1	3	1	2	1	2

Figure 8.7 second cycle of QFD

Figure 8.7 shows the second cycle of QFD utility. Each system characteristic—wall material, operating mechanism, locking type, and wall structure—has been selected. All options for each characteristic have been ranked, and the highest-ranked functional requirements have been chosen. According to the second QFD (figure 8.7), the selected wall material is a double-layered cardboard with a honeycomb core, hardened by being immersed in cement water. This choice was made because it received a score of 140 and ranked first. For the operating mechanism, there are four options: "manual mechanism" with a technical importance score of 116, ranked second; "manual mechanism with a multifunctional exercise machine" with a score of 91, ranked fourth; "manual mechanism with a stationary bike" with a score of 119, ranked first; and "magnetic levitation for movable wall movement" with a score of 98, ranked third. Therefore, the "manual mechanism with a stationary bike," which scored 119 and ranked first, was selected as the operating mechanism. The locking system options include "mechanical locks," which received a technical importance score of 74 and ranked first, and the "electromagnetic locking system," which scored 60 and ranked second. As a result, the mechanical locks, achieved the higher score and were chosen as the locking system. Finally, as the last system characteristic, the wall structure, highlighted with red lines, is discussed. The first option, the Space-Saving Nesting Cupboard Wall System Hidden in a Side Wall, achieved a score of 120 and ranked first, making it the selected choice. In contrast, the Folding Movable Wall System Hidden in a Side Wall, with a score of 102 and ranked second, was not selected.

8.5 Conclusion

In this research, a new cycle of Archi-TRIZ and QFD is applied to demonstrate its utility in enhancing the movable wall by incorporating additional features and finding innovative solutions for each design detail. We then scored and ranked the functional requirements, selecting the top-ranked option to maximize customer satisfaction.

8.6 Future works

It is possible to apply the Archi-TRIZ and QFD methodology in multiple cycles for different examples to refine BNSC based on customer needs. Additionally, specific matrices could be introduced for various fields of civil engineering in the future.

CONCLUSION

This thesis introduces a new methodology that has two main parts. The first part of the methodology is a specialized contradiction matrix that comes from TRIZ and is called Archi-TRIZ. Archi-TRIZ could be useful in building design, especially in designing the non-structural components (NSCs) of the building. The second part of the methodology is QFD, which serves two purposes. First, QFD is a decision-making methodology that could help the designer to choose the better option developed using Archi-TRIZ. Second, it could help to add more features to the chosen option by considering customer needs. So, QFD could help to increase customer satisfaction. This methodology could be applied twice, or even several times, to achieve a better outcome in production.

This thesis had two main objectives that included preparing Archi-TRIZ and adding customer needs through QFD. Archi-TRIZ have been described in chapter 5 and QFD has been utilized in chapter 7 and 8. It also includes some sub-objectives, such as introducing a website or mobile application to host this methodology and help accelerate innovation in the building design process. The structure and layout of the mobile application have been illustrated and described in Chapters 5 and 6, respectively.

In Chapter 6, several examples of forty inventive principles were gathered and described to support brainstorming for civil engineers, to help the designer generate creative ideas in different construction projects. This part is an additional feature that has been illustrated in several tables and pictures with descriptions, which could be added to the proposed mobile application or website. This application could help designers and civil engineers to accelerate innovation in the construction industry. So, it could be useful in building design and the construction industry.

The QFD that has been used to choose better options and add features to the product based on customers' needs and the voice of the engineer to increase customer satisfaction could also be utilized in the building industry.

RECOMMENDATIONS

As for future work, there are several options that could be done. It is possible to integrate all parts of this thesis into a mobile application or even a website and create an innovation-based mobile application that could help designers accelerate innovation in the building design process and the construction industry.

Since there are many fields in civil engineering, including road design, bridge design, building design, infrastructure, wind turbine structures, renewable energy methods, offshore infrastructure, and hydraulic structures, it is possible to develop different specialized contradiction matrices, which could be called Hydro-TRIZ, Road-TRIZ, Structure-TRIZ, Renewable-Energy-TRIZ, etc.

These specialized matrices could be added to the proposed mobile application or website to help designers in different fields of civil engineering accelerate innovation in various projects. It is also possible to add more inventive examples for each field of the construction industry to help engineers.

APPENDIX I

ARCHI-TRIZ

In this appendix, all the steps of preparing Archi-TRIZ have been illustrated.

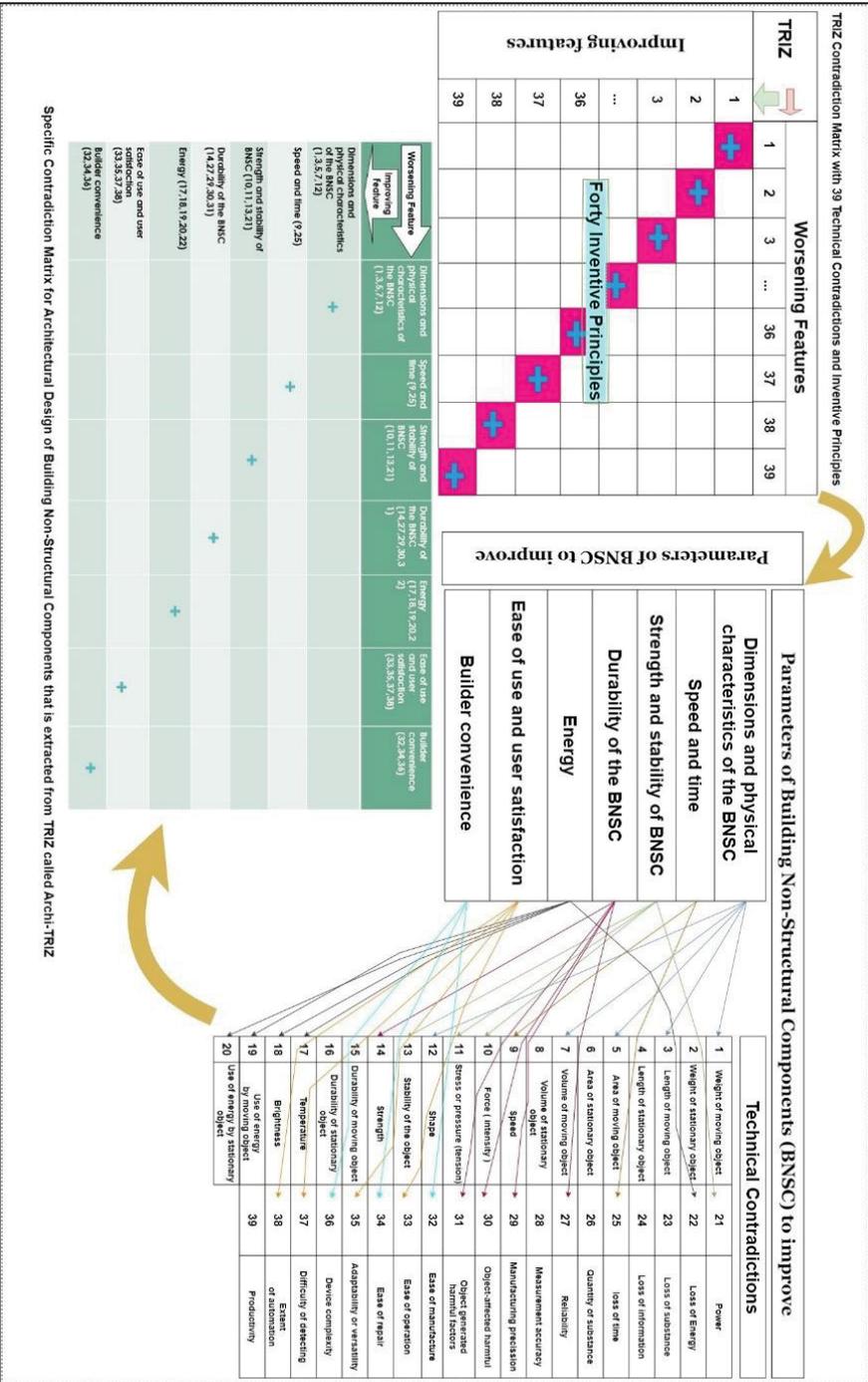


Figure-A I-1 Preparing Archi-TRIZ

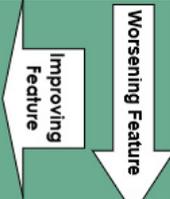
 Worsening Feature ↓ Improving Feature	Dimensions and physical characteristics of the BNSC (1,3,5,7,12)	Speed and time (9,25)	Strength and stability of BNSC (10,11,13,21)	Durability of the BNSC (14,27,29,30,31)	Energy (17,18,19,20,22)	Ease of use and user satisfaction (33,35,37,38)	Builder convenience (32,34,36)
Dimensions and physical characteristics of the Building non-structural component (BNSC) (1,3,5,7,12)	+	2, 8, 15, 38 13, 4, 8 29, 30, 4, 34 29, 4, 38, 34 35, 15, 34, 18 = 34,29,38	8,10,18,37,10,36, 37,40,1,35,19, 39,12,36,18,31 =10,18,36,37 17,10,4,1,8,35, 1,8,15,34,1,35 =1,8,35 19,30,35,2 10,15,36,28 11,2,13,39 19,10,32,18 =10,19,2 15,35,36,37 6,35,36,37 28,10,1,39 35,6,13,18 =35,36,37 35,10,37,40 34,15,10,14 33,1,18,4 32,35,27,31 =10,35,33,31	28,27,18,40,8,35,29,34,3, 15,40,14,9,14,15,7,30,14, 10,40 =14,40,15,7 29,9,14,1,40,11,10,40,16 1,3,11,27,10,14,29,40 =40,14,29,11,9 28,35,26,18,10,28,29,37 2,32,25,28,2,16,32,30,40 =28,32 22,21,18,27 1,15,17,24 22,33,28,1 22,1,27,35 22,1,2,35 =22,1,21,27,35,33 22,35,31,39,17,15,17,2, 18,39,17,2,40,1,35,1 =17,1,2,35,39,(30,31)	6,29,4,38,10,15, 19,2,15,16,34, 39,10,18,22, 14,19,32 =10,15,19,38 19,1,32,32,15, 32,19,13,2,13, 10,13,15,32 =32,13,19 35,12,34,31,8, 35,24,19,32,35,2 ,6,34,14 =35,34 6,2,34,19,7,2, 35,39,15,17, 30,26,7,15,13, 16,14 =2,7,15,39	35,3,2,24,15,29, 35,4,15,17,13, 16,15,13,30,12,3 2,15,26 =15,13,35 29,5,15,8,14,15,1 ,16,15,30,15,29,1 ,15,29 =15,29,1 28,29,26,32,35, 1,26,24,2,36,26,1 8,29,26,4,15,13, 39 =26,29 26,35,18,19,17, 24,26,16,14,30, 28,23,35,34,16, 24,15,1,32 =26,35,24,(30,14)	27,28,1,36,1, 29,17,13,1,26, 24,29,1,40,1, 32,17,28 =1,28 2,27,28,11,1, 28,10,15,13,10 ,1,10,2,13,1 =1,10,2,28,13,11 26,30,36,34 1,19,26,24,14, 1,13,26,1,16, 29,1,28 =1,26

Figure-A I-2 Step 1 of preparing Archi-TRIZ

 	Dimensions and physical characteristics of the BNSC (1,3,5,7,12)	Speed and time (9,25)	Strength and stability of BNSC (10,11,13,21)	Durability of the BNSC (14,27,29,30,31)	Energy (17,18,19,20,22)	Ease of use and user satisfaction (33,35,37,38)	Builder convenience (32,34,36)
Speed and time (9,25)	2,28,13,38,13,14,8,29,30,34,7,29,34,35,15,18,34= 34,13,29,7,38	+	13,28,15,19,6,18,38,40,28,33,1,18,19,35,38,2 = 38,19,28,33	8,3,26,14,11,35,27,28,10,28,32,25,1,28,35,23,2,24,35,21 = 35,28,11	28,30,36,2,10,13,19,8,15,35,38,14,20,19,35 = 35,19,20	32,28,13,12,15,10,26,3,3,4,27,16,10,1,8= 10,18,32	35,13,8,1,34,2,28,27,10,28,4,34 = 28,34
	10,20,37,35,15,2,29,26,4,5,16,2,5,34,10,4,10,34,17 = 10,34,4,5,20		10,37,36,5,37,3,6,4,35,3,22,5,3,5,20,10,6= 37,35,36,5,20	29,3,28,18,10,30,4,24,26,28,18,3,5,18,34,35,22,18,39= 18,28,35	35,29,21,18,1,19,26,17,35,38,19,18,1,10,5,18,32 = 18,1,35,38	4,28,10,34,3,5,28,18,28,3,2,10,24,28,3,5,30= 28,35,10	35,28,34,4,32,1,10,6,29 = 35,1,4,10

Figure-A I-3 Step 2 of preparing Archi-TRIZ

<div style="text-align: center;"> Worsening Feature Improving Feature </div>	Dimensions and physical characteristics of the BNSC (1,3,5,7,12)	Speed and time (9,25)	Strength and stability of the BNSC (10,11,13,21)	Durability of the BNSC (14,27,29,30,31)	Energy (17,18,19,20,22)	Ease of use and user satisfaction (33,35,37,38)	Builder convenience (32,34,36)
Strength and stability of Building non-structural component(BNSC) (10,11,13,21)	8, 1, 37, 18, 10, 36, 37, 40, 21, 35, 2, 39, 8, 36, 38, 31= 8,36,37,31 17, 19, 9, 36, 35, 10, 36, 13, 15, 1, 28, 1, 10, 35, 37= 10,36,37	13, 28, 15, 12, 6, 35, 36, 33, 15, 28, 18, 15, 35, 2= 15,28,35, 33	+	35, 10, 14, 27, 9, 18, 3, 40, 17, 9, 15, 26, 10, 28= 9,10 2, 35, 16, 11, 35, 27, 28, 10, 13, 19, 35, 19, 21, 11, 27= 11,19,27,35 28, 29, 37, 36, 3, 35, 18= 3,18,28,35 1, 35, 40, 18, 22, 2, 37, 35, 24, 30, 18, 1, 35, 6, 27= 1,18,35 13, 3, 36, 24, 2, 33, 27, 18, 35, 40, 27, 39, 2, 35, 6= 2,27,35,33	35, 10, 21, 19, 17, 10, 1, 16, 36, 37, 14, 15= 10 35, 39, 19, 2, 14, 24, 10, 37, 2, 36, 25= 10,2,14 35, 1, 32, 32, 3, 27, 16, 13, 19, 27, 4, 29, 18, 14, 2, 39, 6 27,16	1, 28, 3, 25, 11, 32, 35, 30, 26, 35, 10= 35,11 15, 17, 18, 20, 35, 35, 30, 34, 2, 19, 17, 34= 17,34,35,30,20 36, 37, 10, 19, 2, 36, 37, 35, 22, 39, 23, 19, 35, 16= 19,35,36,37	15, 37, 18, 1, 1, 35, 16, 35, 19, 26, 10, 34 = 1,35 15, 1, 11, 2, 2, 35, 10, 16, 35, 2, 10, 34 = 2,10,35,11 26, 35, 10, 18, 19, 1, 35, 2, 35, 22, 26, 20, 19, 30, 34= 19,26,35,20
	15, 9, 12, 37, 6, 35, 10, 28, 10, 19, 39, 35, 6, 38= 10,35,9,38 10, 35, 40, 34, 35, 4, 15, 10, 22, 1, 18, 4, 29, 14, 2, 40= 4,10,35,40	10, 37, 36, 37, 36, 4, 35, 27, 35, 20, 10, 6= 10,35,36, 37,20			2, 14, 17, 25, 16, 6, 19, 16, 6, 19, 37, 10, 35, 38= 2,16,19,35,(25, 38)	2, 35, 35, 24, 1, 8, 35, 28, 2, 17= 2,35	

Figure-A I-4 Step 3 of preparing Archi-TRIZ

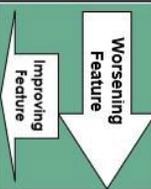
	Dimensions and physical characteristics of the BNSC (1,3,5,7,12)	Speed and time (9,25)	Strength and stability of BNSC (10,11,13,21)	Durability of the BNSC (14,27,29,30,31)	Energy (17,18,19,20,22)	Ease of use and user satisfaction (33,35,37,38)	Builder convenience (32,34,36)
Durability of the Building non-structural component (BNSC) (14,27,29,30,31)	1,8,40,15,1,15,8,35,3,34,40,29,10,15,14,7,10,30,35,40,	8,13,26,14,29,3,28,10,21,35,11,28,10,30,4,	10,18,3,14,10,3,18,40,13,17,35,10,26,35,28,8,28,10,3,10,24,35,19,21,11,26,31,	+ 10,28,32,32,26,28,18,21,22,35,28,35,18,34,28,19,34,36,3,35,30,18,32,2,	30,10,40,35,19,19,35,10,35,35,3,35,10,11,32,13,21,11,27,19,36,23,10,11,35,	32,40,25,2,15,3,32,27,3,15,40,15,27,17,40,13,35,8,24,27,40,28,11,13,27,	11,3,10,32,27,11,3,2,13,25,28,1,11,13,35,1,25,10,26,2,18,
	3,8,10,40,15,9,14,4,17,10,14,16,3,10,14,24,35,1,16,11,	10,28,32,32,26,28,18,	10,24,35,19,21,11,26,31,	19,26,3,32,32,2,13,32,2,	1,11,27,19,36,23,10,11,35,	27,17,40,13,35,8,24,27,40,28,11,13,27,	24,35,2,35,10,2,22,19,29,40,
	28,32,13,18,10,28,29,37,28,33,29,32,32,23,2,32,30,40,	21,22,35,28,35,18,34,35,28,3,23,1,22,	28,19,34,36,3,35,30,18,32,2,	22,33,35,2,1,19,32,13,1,24,6,27,10,2,22,37,21,22,35,2,	32,40,25,2,15,3,32,27,3,15,40,15,	1,32,35,23,26,28,18,23,	19,1,31,=
	22,21,27,39,17,1,39,4,22,1,33,28,22,23,37,35,22,1,3,35,	28,35,10,(3,18,21,22,26,32,11)	13,35,39,18,22,2,37,35,24,30,18,19,22,31,2,	22,35,2,24,19,24,39,32,2,35,6,19,22,18,21,35,2,22,	27,40,2,(3,15,32,35,25,23,11,31,33)	33,3,34,2,21,27,1,2,	2,1,10,11,35,(25,31)
	19,22,15,39,17,15,16,22,17,2,18,39,17,2,40,35,1,		35,28,1,40,2,33,27,18,35,40,27,39,2,35,18,	35,2,19,32,10,22,(24,21,11,33)			
	1,10,15,22,35,40,(8,4,9,7,23,30,14,11,33)		35,18,2,10,3,28,(30,11,31,33)				

Figure-A I-5 Step 4 of preparing Archi-TRIZ

Worsening Feature ↓ Improving Feature	Dimensions and physical characteristics of the BNSC (1,3,5,7,12)	Speed and time (9,25)	Strength and stability of BNSC (10,11,13,21)	Durability of the BNSC (14,27,29,30,31)	Energy (17,18,19,20,22)	Ease of use and user satisfaction (33,35,37,38)	Builder convenience (32,34,36)
Energy (17,18,19,20,22)	36,22,6,38, 15,19,9, 3,35,39,18, 34,39,40,18, 14,22,19,32,	2,28,36,30, 35,28,21,18, 10,13,19, 19,1,26,17, 8,35, 35,38,19,18,	35,10,3,21, 35,39,19,2, 1,35,32, 2,14,17,25, 26,19,6, 32,3,27, 32,	10,30,22,40, 19,35,3,10, 24, 22,33,35,2, 22,35,2,24, 35,19, 3,32, 15,19, 35,19,32,39,		26,27, 2,18,27, 3,27,35,31, 26,2,19,16, 28,26,19, 15,1,19, 32,15, 2,26,10,	26,27, 4,10,16, 2,17,16, 19,35,28,26, 15,17,13,16, 6,32,13, 28,26,30, 1,15,17,28, 2,29,27,28,
	19,1,32, 19,32,16, 19,32,26, 2,13,10, 32,30, 12,18,28,31, 12,28, 15,19,25, 35,13,18, 12,2,29, 15,6,19,28, 7,2,6,13, 15,26,17,30, 7,18,23 = 19,18,32,15,(2,6,12, 13,28,7,30,31)	16,35,38, 10,18,32,7, = 35,18,19,(10,28, 38,7)	16,26,21,2, 23,14,25, 19,13,17,24, 6,19,37,18, 36,37, 27,4,29,18, = 19,2,32,35 ,14,21	5,19,9,35, 19,21,11,27, 1,35,6,27, 2,35,6, 35, 10,36,23, 10,2,22,37, 19,22,18, 26, 11,10,35, 21,22,35,2, 21,35,2,22, = 35,2,19,22,3, (11,21,33)	+	19,35, 15,17,13,16, 35,38, 32,2, 19,35,16,25, 35,32,1, 35,3,15,23, 2, = 35,2,19,(15,26, 31)	1,4, 2,19, 7,23 = 28,2,16,17,26,7

Figure-A I-6 Step 5 of preparing Archi-TRIZ

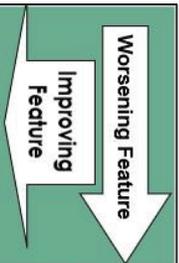
	Dimensions and characteristics of the BNSC (1,3,5,7,12)	Speed and time (9,25)	Strength and stability of BNSC (10,11,13,21)	Durability of the BNSC (14,27,29,30,31)	Energy (17,18,19,20,22)	Ease of use and user satisfaction (33,35,37,38)	Builder convenience (32,34,36)
Ease of use and user satisfaction (33,35,37,38)	25,2,13,15,1,17,13,12,1,17,13,16,1,16,35,15,15,34,29,28,	18,13,34,4,28,10,34,	28,13,35,2,32,12,32,35,30,35,34,2,10,	32,40,3,28,17,27,8,40,1,32,35,23,2,25,28,39,	26,27,13,13,17,1,24,1,13,24,2,19,13,	+	2,5,12,12,26,1,32,32,26,12,17,
	1,6,15,8,35,1,29,2,35,30,29,7,15,35,29,15,37,1,8,	3,4,16,35,18,28,32,9,28,10,24,28,35,30	15,17,20,35,16,35,30,14,19,1,29	35,3,32,6,35,13,8,24,35,11,32,31,	27,2,3,35,6,22,26,1,19,35,29,13,18,15,1,		1,13,31,1,16,7,4,15,29,37,28,
16,17,26,24,2,13,18,17,29,1,4,16,27,13,1,39,	28,10,24,28,35,30 = 28,35,10(4,34)	30,28,40,19,35,36,37,32,11,22,39,30,18,1,16,10,	27,3,15,28,27,40,28,8,22,19,29,28,2,21	3,27,35,16,2,24,26,35,38,19,35,16,35,3,15,19,	1,26,13,1,35,13,15,24,10 =		
28,26,18,35,14,13,17,28,17,14,13,35,13,16,15,32,1,13 =	2,35,13,35,18,1,28,2,27 =	25,13,11,27,32,28,26,18,23,2,33,2 =	28,32,2,27,35(3,8,40,23,31,11,33)	26,2,19,8,32,19,2,32,13,23,28 =	1,13,26(13,28,12,5,7,31)		
1,13,15,17,35(16,28,29,7,14)	1,13,15,17,35(16,28,29,7,14)	35,30,2(1,28,32,20,39)	28,32,2,27,35(3,8,40,23,31,11,33)	13,19,35,2(1,26,38)	1,13,26(13,28,12,5,7,31)		

Figure-A I-7 Step 6 of preparing Archi-TRIZ

 Worsening Feature  Improving Feature	Dimensions and physical characteristics of the BNSC (1,3,5,7,12)	Speed and time (9,25)	Strength and stability of BNSC (10,11,13,21)	Durability of the BNSC (14,27,29,30,31)	Energy (17,18,19,20,22)	Ease of use and user satisfaction (33,35,37,38)	Builder convenience (32,34,36)
Builder convenience (32,34,36)	28, 29, 15, 16, 1, 29, 13, 17, 13, 1, 26, 12, 13, 29, 1, 40, 1, 28, 13, 27	35, 13, 8, 1, 35, 28, 34, 4 34, 9, 32, 1, 10, 25	35, 12, 35, 19, 1, 37, 11, 13, 1, 27, 1, 12, 24	1, 3, 10, 32, 24, 2 11, 1, 2, 9, 11, 10, 1, 16, 25, 10, 35, 10, 2, 16	27, 26, 18, 28, 24, 27, 1, 28, 26, 27, 1, 1, 4, 19, 35	2, 5, 13, 16, 2, 13, 15, 6, 28, 11, 1, 8, 28, 1	+
	2, 27, 35, 11, 1, 28, 10, 25, 15, 13, 32, 25, 2, 35, 11, 1, 13, 2, 4	34, 10, 28 6, 29 = 34, 1, 10, 28, 35	1, 11, 10, 13, 2, 35, 15, 10, 32, 2	2, 13, 28, 13, 35, 1, 26, 24, 32, 22, 19, 29, 40, 19, 1	4, 10, 15, 1, 13, 15, 1, 28, 16, 15, 1, 32, 19	1, 12, 26, 15, 7, 1, 4, 16, 34, 35, 7, 13	
	26, 30, 34, 36, 1, 19, 26, 24, 14, 1, 13, 16, 34, 26, 6, 29, 13, 28, 15	26, 16, 19, 1, 35, 2, 22, 17, 19, 20, 19, 30, 34 = 1, 19, 35, 2, (12, 20, 11)	26, 16, 19, 1, 35, 2, 22, 17, 19, 20, 19, 30, 34 = 1, 19, 35, 2, (12, 20, 11)	2, 17, 13, 24, 17, 13, 19, 1	27, 2, 29, 28, 10, 35, 13, 2 = 1, 13, 27, 28	27, 9, 26, 24, 29, 15, 28, 37, 15, 10, 37, 28, 15, 1, 24 = 1, 15, 28, 13, 16, 7, 11	
	1, 13, 26, 28, 29, 11						

Figure-A I-8 Step 7 of preparing Archi-TRIZ

Worsening Feature ↓ Improving Feature ↑	Dimensions and physical characteristics of the BNSC (1,3,5,7,12)	Speed and time (9,25)	Strength and stability of BNSC (10,11,13,21)	Durability of the BNSC (14,27,29,30,31)	Energy (17,18,19,20,22)	Ease of use and user satisfaction (33,35,37,38)	Builder convenience (32,34,36)
Dimensions and physical characteristics of the BNSC (1,3,5,7,12)		29,10,8,15,20,38	10,35,1,(18,36,37,33,21,31)	40,1,35,(14,28,22,2,33,39,9,30,7,11,31)	15,19,32,2,(34,35,39,7,31,38)	15,26,29,(35,1,24,30)	1,28,13,26,(11)
Speed and time (9,25)	34,29,10,2,(13,4,5,35,20,7,38)	+	35,6,(5,10,19,28,36,37,38,20,33)	35,28,18,(3,24,26,11)	35,19,18,1,(5,20,38)	28,10,(18,32,34,35)	28,34,(1,4,10,35)
Strength and stability of BNSC (10,11,13,21)	10,35,15,36,(31,9,11,38)	35,36,15,(10,28,37,6,20,33)	+	35,27,18,2,(9,11,33)	2,10,14,16,(19,35,(25,38)	35,2,17,19,(30,20,11)	35,10,1,(2,19,26,20,11)
Durability of the BNSC (14,27,29,30,31)	1,10,15,22,35,40,(8,4,9,7,23,30,11,33)	28,35,10,(3,18,21,22,26,32,11)	35,18,2,10,3,28,(30,11,31,33)	+	35,2,19,32,10,(22,(24,21,11,33)	27,40,2,(3,15,32,35,25,23,11,31,33)	2,1,10,11,35,(25,31)
Energy (17,18,19,20,22)	19,18,32,15,(2,6,12,13,28,7,30,31)	35,18,19,(10,28,38,7)	19,2,32,35,21	35,2,19,22,3,11,21,33	+	35,2,19,(15,26,31)	28,2,16,17,26,7
Ease of use and user satisfaction (33,35,37,38)	1,13,15,17,35,(16,28,29,7)	28,35,10,(4,34)	35,30,2,(1,28,32,20,39)	28,32,2,27,35,(3,8,40,23,31,1,1,33)	13,19,35,2,(1,26,38)	+	1,13,26,(13,28,12,5,7,11,31)
Builder convenience (32,34,36)	1,13,26,28,29,(11)	34,1,10,28,35	1,19,35,2,(12,20,11)	1,2,11	1,13,27,28	1,15,28,13,16,(7,11)	+

Figure-A I-9 Archi-TRIZ

APPENDIX II

QFD

This appendix illustrates larger versions of the rotated QFD matrices from Chapters 7 and 8.

1: low, 5: high Customer importance rating	Functional Requirements (How's) → Customer Requirements - (What's) ↓	Wall Material		Operating Mechanisms				Locking Type		Wall Structure	
		Wood Wall	Honeycomb cardboard hardened with cement water	Manual Mechanism	Manual Mechanism with Multifunctional Exercise Machine	Manual Mechanism with stationary bike	Magnetic Levitation for Movable Wall Movement	Mechanical Locks	Electromagnetic Locking System	Space-Saving Nesting Cardboard Wall System hidden in a Side Wall	Folding Movable Wall System hidden in a Side Wall
5	Cost	1	5	4	3	3	2	3	2	5	4
4	Safety	3	4	4	4	5	3			4	3
3	ease of use	2	3	2	3	4	5				
2	light weight	1	5	4	2	3	4	4	3	5	3
4	Attractive design	5	5							4	4
5	Quiet	4	5	4	3	4	4	4	4	5	4
4	Warranty and support	4	3	4	3	4	3				
2	Environmental sustainability	5	4	5	5	5	3	3	2	4	5
5	Durability and longevity	4	3	4	2	4	3	5	4	4	5
Technical importance score		111	140	116	91	119	98	74	60	120	109
Importance %		25%	31%	26%	20%	26%	22%	16%	13%	26%	24%
Priorities rank		2	1	2	4	1	3	1	2	1	2

Figure-A II-2 QFD

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