A New Method for Architecture Space Design Based on Substance-Field Analysis

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Abstract. Research about novel methods in the architectural design process can enlarge design researches. Structured design methods can make the design process more organized and learnable. Substance-Field (Su-field) Analysis is a TRIZ analytical tool for modeling problems related to existing technological systems. Meanwhile, the space concept is vital in architecture. This paper aims to present Human-Field (Hu-field) Analysis method based on Su-field Analysis and general solutions for more effective architecture space design. A controlled experiment demonstrates the effectiveness of this method by measuring idea quality and quantity.

1. Introduction

TRIZ (theory of inventive problem-solving method) is a systematic approach which successfully reveals the inherent laws and principles of creating inventions. Focusing on clarifying and emphasizing the contradictions existing in the system, its goal is to completely resolve the contradictions and obtain the final ideal solution [1]. The major tools and methods of TRIZ include ‘40 inventive principles’, ‘Su-field Analysis’, ‘76 General solutions’ and ‘evolution analysis’.

Many applications of TRIZ theory in architecture has been presented. Mann [2] explained the TRIZ theory to train students in architecture design education. Padmanabhan [3] affirmed and solved the problem of increasing wind power in buildings using TRIZ Tool in cities by an experimental method. Ruey-Sen [4] explored TRIZ application for the improvement of heat insulation for roof steel plates. Kankey [5] also discussed improving the acoustics in a historic building using TRIZ. However, these researches primarily focus on applying TRIZ theory in construction technology field, the difficulties of applying TRIZ theory in architecture design process are due to architecture’s attributes, Rittel [6] and Cross [7] characterized it as wicked problems. More specific, the architecture design process is based on fuzzy or ambiguous information, with undefined problem requirements and conflicting parameters as well as a lack of general solution methods [8]. As a result, these attributes explain the complexity inherent in the architecture design process, the decomposition of which into the building and solving problems has reached wider research fields, including cognitive psychology.

Herein, a new method and general solutions for more effective architecture space design based on Su-field Analysis model are presented to demonstrate the potential of TRIZ theory in architecture design process. In addition, a control experiment demonstrates the effectiveness of this method by measuring idea quality and quantity.
2. Related Works & The New Method for Architecture Space Design

In TRIZ theory, Su-field Analysis is an analytical tool for modeling problems related to existing technological systems. The desired function is the output from an object or substance (S1), caused by another object (S2) with the help of some means (types of energy, F) [9] [10] [11]. Figure 1 shows the basic model of Su-field Analysis.

![Figure 1. The basic model of Su-field Analysis](image)

2.1. Human-field (Hu-field) Analysis

For architecture space design, we define S1 is human and S2 is the spatial element. Hence, we present the Human-field Analysis as the new method for architecture space design.

![Figure 2. The basic model of Hu-field Analysis](image)

There are four basic principles included in Hu-field Analysis:
1. Effective complete architecture space system contains human, spatial elements and field.
2. Incomplete architecture space system requires completion or a new space system.
3. Ineffective complete architecture space system requires improvement to create the desired space.
4. Negative complete architecture space system requires the elimination of the negative effect.

2.2. Making a model

The field in Hu-field Analysis, which is often space form, space combination, space order, proportion, and scale. The effect of architecture space could be on human from the output of the field information. The term field is used in the broadest sense, including the fields of physics and psychology. A complete architecture space model is a triad of human, spatial elements and a field.

The innovative problem is modeled to show the relationships among spatial elements, human and the field. Complex systems can be modeled by multiple, connected Hu-field Models.

There are four steps to follow in making the Hu-field Model:
1. Identify the spatial elements. Spatial elements comprise architecture space which is either acting upon human or is within substance 2 as a system.
2. Construct the model. After completing these two steps, stop to assess the completeness and effectiveness of the system. If some element is missing, try to identify what it is or find the substitute.
3. Consider design solutions from the General Solutions.
4. Develop a concept to support the solution. In following Steps 3 and 4, activity shifts to other knowledge-based tools.

2.3. Analysis Nomenclature

In Hu-field Analysis model, the human is the recipient of the system action. Spatial elements are the means by which field can be achieved. We abstract spatial element as:

(Po) — Point
(Li) — Line
(Su) — Surface

There are six different connecting relationships between the spatial element and human expressed by different symbols and shown in Figure 3.
2.4. General solutions
There are 5 general solutions in Hu-field Analysis based on the 7 general solutions in Su-field Analysis [11].

- General Solution 1: Complete an Incomplete Hu-Field Model
  Complete a Hu-field model if any of its three components is missing.

- General Solution 2: Modify Spatial Elements to Eliminate or Reduce Negative Impact
  Designers can change internally or externally and temporarily or permanently the characteristics of spatial elements to eliminate or reduce the negative impact on the human in architecture space.

- General Solution 3: Change Existing Field to Reduce or Eliminate Negative Impact
  Reconsider or change the existing field in Hu-field model to reduce or eliminate negative impact.

- General Solution 4: Eliminate, Neutralize or Isolate Negative Impact by Introducing a Positive Field
  When the current architecture space has the negative impact on human, designers can introduce a positive field to increase the positive effect and reduce the negative effect of architecture space. For example, when the architecture space is too narrow, which belongs to the ‘scale field’, ‘color field’ can be introduced where light and cool color can make space large and bright.

- General Solution 5: Expand Existing Hu-Field Model to a Chain
  Expand the existing Hu-field model to a chain by introducing a new Sub-Hu-field model to the system.

3. Data Collection and Analysis
In this study, we use a control experiment demonstrates the effectiveness of this method by measuring idea quality and quantity.

3.1. Participants
In this experiment, participants consisted of 16 students pursuing the bachelor of architecture in the same university, they all completed the basic architecture course and got the credits.

3.2. Analysis of Idea Quality
In this study, we adopt the method presented by Shah, Smith, and Vargas-Hernandez [12]. In this method, idea quality can be sufficiently estimated even though there is not enough quantitative information to do formal analysis at the concept stage. In addition, this method adds all the quality scores for all the alternatives to achieve the total score for the set. As a result, the idea quality is defined as:

\[
M = \sum_{j=1}^{m} \sum_{k=1}^{n} S_{jk}p_k \cdot f_j
\]
In this equation, $S_{jk}$ is the score for quality for function $j$ at stage $k$; $m$ is the total number of functions; $f_j$ is the weight for function $j$; $p_k$ is the weight for stage $k$. The denominator is for normalizing to a scale of 10.

3.3. Experiment process
The 16 participants were divided into Group A and Group B, they were all asked to design play space for children under 12 years old in an hour. The difference is that Group A used Hu-field Analysis in the whole design process, whereas Group B completed the design task without Hu-field Analysis.

3.4. Experiment results
Finally, we got all the design ideas from the 16 participants and Table 1 shows the idea of quality and evaluated them by measuring their quality and quantity. Table 1 shows the idea quality and quantity of each participant.

| Table 1. Idea quality and quantity of each participant |
|-----------------------------------------------------|
| Group | Idea Quality | Idea Quantity | Group | Idea Quality | Idea Quantity |
|-------|--------------|---------------|-------|--------------|---------------|
| A1    | 6.15         | 3             | B1    | 4.14         | 2             |
| A2    | 5.64         | 2             | B2    | 3.56         | 3             |
| A3    | 4.96         | 4             | B3    | 4.07         | 2             |
| A4    | 6.54         | 3             | B4    | 4.21         | 1             |
| A5    | 5.46         | 4             | B5    | 5.13         | 3             |
| A6    | 4.87         | 3             | B6    | 3.76         | 2             |
| A7    | 5.12         | 6             | B7    | 4.28         | 2             |
| A8    | 5.98         | 4             | B8    | 5.76         | 3             |

Then we analyzed these data with Paired-Samples T-test, Table 2 shows the result.

| Table 2. The result of the Paired Sample T-test |
|------------------------------------------------|
| Group | Idea Quality $\bar{X}$ | Idea Quality SD | Sig | Idea Quantity $\bar{X}$ | Idea Quantity SD | Sig |
|-------|------------------------|-----------------|-----|------------------------|-----------------|-----|
| A     | 5.59                   | 0.60            | 0.04| 3.63                   | 1.19            | 0.028|
| B     | 4.36                   | 0.73            | <0.05| 2.25                   | 0.71            | <0.05|

Both the results of idea quality and idea quantity are significant, it can indicate that Hu-field Analysis is an effective tool in architecture space design as it has the ability to promote both participants’ idea quality and idea quantity.

4. Discussion
Su-field Analysis is an analytical tool in TRIZ which related to solving technological problems. In this study, we deconstruct Su-field Analysis and present Hu-field Analysis, however, the human is a more complex system relative to technique system. Therefore, when applying the Hu-field Analysis, it is crucial for designers to analyze and understand the needs of human.

Hu-field Analysis can also be expanded to other human centered design fields such as environmental design, interaction design, clothes design and service design. Taken together, Hu-field Analysis requires the deep understandings of human and it may prepare designers for capturing core values in the broad field of design.

5. Conclusion
In this article, we present Hu-field Analysis for architecture space design and conduct a control experiment to demonstrates the effectiveness of this method by measuring idea quality and quantity. However, ideation effectiveness also includes idea novelty and idea variety, as well as Hu-field Analysis
in architecture space design, needs to be explored potentially by conducting more human experiments and considering more design contexts.

References

[1] Savransky, S. D. (2000). Engineering of Creativity: Introduction to TRIZ Methodology of inventive problem-solving. CRC Press.

[2] Mann, D., & Catháin, C. Ó. (2005). Using TRIZ in Architecture: First Steps. The TRIZ Journal.

[3] Padmanabhan, K. K. (2013). Study on increasing wind power in buildings using TRIZ Tool in urban areas. Energy and Buildings, 61, 344-348.

[4] Chiu, R. S., & Cheng, S. T. (2012). The improvement of heat insulation for roof steel plates by triz application. Journal of Marine Science and Technology, 20(2), 122-131.

[5] Kankey, A., & Ogot, M. (2005). Improving the acoustics in a historic building using axiomatic design and TRIZ. The TRIZ Journal.

[6] Grant, D.P. (ed.). (1998). Design methods: Theories, research, education and practice. Impressions of architecture 130. Notes and observations on Professor Horst W.J. Rittel’s classic design methods course at Berkeley as circa-1969–71. California: The Design Methods Institute 32(1), 2599–2638.

[7] Cross, N. (1994). Engineering design methods: Strategies for product design. Chichester: John Wiley & Sons.

[8] Kiatake, M., & Petreche, J. R. D. (2012). A case study on the application of the theory of inventive problem-solving in architecture. Architectural Engineering and Design Management, 8(2), 90-102.

[9] Terninko, J., Zusman, A., & Zlotin, B. (1998). Systematic innovation: an introduction to TRIZ (theory of inventive problem solving). CRC press.

[10] Terninko, J. (2000). Su-field analysis. TRIZ Journal, 2, 23-29.

[11] Mao, X., & Zhang, X. (2007). Generalized solutions for Su-Field analysis. TRIZ Journal.

[12] Shah, J. J., Smith, S. M., & Vargas-Hernandez, N. (2003). Metrics for measuring ideation effectiveness. Design studies, 24(2), 111-134.