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Study of New Wall Materials Design Based on TRIZ Integrated Innovation Method

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Abstract

New wall materials alleviate the problems of high energy consumption and heavy pollution in the production process through the forms of new natural raw materials, energy conservation, land conservation, waste utilization, etc.. In this paper, design of new building wall materials is achieved through the integrated innovation method of Theory of Inventive Problem Solving (TRIZ), Technology Acceptance Model (TAM), and Quality Function Deployment (QFD). Technical contradictions and physical contradictions in various stages of product design and production are resolved from the perspectives of user survey, R & D design, manufacturing, marketing. According to the different advantages of TRIZ, TAM and QFD in various stages of product, new wall material products of Guizhou Long Life Forestry Group are used as an example, with the integrated innovation method, the company's new wall materials products are designed, and green, environmental, economical series wall materials products are designed and marketed in China.

Key words: TRIZ; TAM; QFD; New building materials; Integrated innovation method

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INTRODUCTION

With the progress of society and the continuous improvement of living standards, people are having more demanding requirements on living environment, while meeting people's basic living needs, buildings should also meet high standard requirements such as artistic requirements, green, energy-saving and environmental protection. Wall materials are vital important role in building materials industry, with the usage amount accounting for about 1/2 of all building materials, value accounting for about 30% of total construction cost, output value being nearly 1/3 of total output value of building materials industry, and energy consumption accounting for about 1/2 of total energy consumption of building materials industry (LIU, 2008). The performance and price of wall materials have significant impact on performance, quality and economic efficiency of construction works, new wall materials have solved the high energy consumption, heavy pollution problems in the production process through the forms of new natural raw materials, energy conservation, land conservation, waste utilization, etc. (CHEN, 2011). So innovation of wall materials has great value in the building products application, as well as in the improvement of people's living environment.

Products are the main parts of production and business activities of manufacturing enterprises. However, product development is the source of this activity, which is a process of continuously meeting user needs (ZENG, 2009). The purpose of grasping every stage of product design and manufacturing is to ensure that the products meet user needs. Obviously, how to reduce product costs and improve product performance with new wall materials is the main task of product development and design.

Through TAM, QFD and TRIZ to make a comparative analysis of contradictions in various stages of product development from the perspectives of users, market, R

& D design, manufacturing, and marketing, this paper researches the solution of comprehensive contradictory problems in the product development, production and application process such as user needs, quality control, management and technical contradictions by TAM, QFD and TRIZ integrated innovation method. The new wall building material products of Guizhou Long Life Forestry Group are used as a design case to study the design of the company's new wall materials to enable the application of wall materials to be more reliable, convenient, green and economical.

1. INTEGRATED METHOD APPLICATION OF TAM, QFD, AND TRIZ

In the process of economic globalization, with the continuous development of economy and technology, manufacturers of building materials and building contractors are facing fierce market competition. Consumers also have ever increasing requirements for the design of building products, the range, quality, technological evolution speed, innovation degree of product are all facing new challenges, and product design is also developing from single design into collaboration between business and organizations in the virtual environment. TAM has advantages in product demand and market analysis, QFD in demand design and product performance design, and TRIZ in product concept design and contradiction problem solving. The integrated innovation method which combines TRIZ, TAM, and QFD can exactly solve main contradictory problems in the process from the product demand analysis to the product design, production, and application.

1.1 Overview of TAM/QFD/TRIZ

1.1.1 Technology Acceptance Model (TAM)

With growing technology needs in the 1970's, and increasing failures of system adoption in organizations, predicting system use became an area of interest for many researchers. However, most of the studies carried out failed to produce reliable measures that could explain system acceptance or rejection (Davis, 1989). In 1985, Fred Davis proposed the Technology Acceptance Model (TAM) in his doctoral thesis at the MIT Sloan School of Management (Davis, 1985). He proposed that system use is a response that can be explained or predicted by user motivation, which, in turn, is directly influenced by an external stimulus consisting of the actual system's features and capabilities.

By relying on prior work by Fishbein and Ajzen (1975), who formulated the Theory of Reasoned Action, and other related research studies, Davis further refined his conceptual model to propose the Technology Acceptance Model as shown in Figure 1.

In this proposal, Davis (1985) suggested that users' motivation can be explained by three factors: Perceived Ease of Use, Perceived Usefulness, and Attitude Toward Using the system. He hypothesized that the attitude of a user toward a system was a major determinant of whether the user will actually use or reject the system. The attitude of the user, in turn, was considered to be influenced by two major beliefs: Perceived usefulness and perceived ease of use, with perceived ease of use having a direct influence on perceived usefulness. Finally, both these beliefs were hypothesized to be directly influenced by the system design characteristics, represented by X1, X2, and X3 in Figure 1.

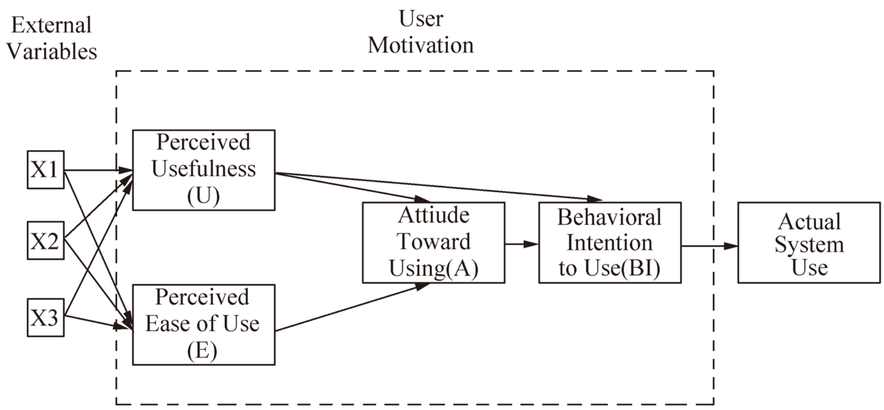


Figure 1
The Technology Acceptance Model

During later experimentation stages, Davis (1985) would refine his model to include other variables and modify the relationships that he initially formulated. Similarly, other researchers would apply and propose several additions to the Technology Acceptance Model, such that over time, TAM evolved into a leading model in explaining and predicting system use. In fact, TAM has become so popular that it has been cited in most of the researches that deal with user acceptance of technology. However, some researchers claim that TAM may have attracted more easy and quick research, such that less attention has been given to the real problem of technology acceptance (Lee, Kozar, & Larsen, 2003). Today, research on technology acceptance is still on going. TAM has been expanded and improved. Models such as TAM2, UTAUT have improved (Venkatesh & Davis, 2000; Chuttur, 2009; Venkatesh & Bala, 2008). These models have been widely applied to various technological occasions, in the studies of user behavior prediction and user acceptance of various information technologies. TAM has all demonstrated its effectiveness. The theory has gained wide use in the theories of information system prediction and user behavior analysis.

1.1.2 Quality Function Deployment (QFD)

Quality Function Deployment (QFD) is a multi-level deductive analytical method which transforms customer or market demands into design requirements, component parts characteristics, process requirements, and production requirements. It was originated in the early 1970s in Japan's Mitsubishi Heavy Industries by Yoji Akao (Akao, 1990). U.S. Ford Motor Company was the first to use the QFD method (Mazur, 1993). In 1983, professors Masao Kogure and Yoji Akao published an article titled "Quality Function Deployment and CWQC in Japan" in the American Society for Quality (ASQ) magazine "Quality Progress". QFD has been widely used in the automotive, home appliance, garment, integrated circuit, mechanical, medical and education industries (Das & Pradhan, 2011; LIU & SUN, 2005; ZHAO, 1994; CHEN, GUO, & GAO, 2011; WANG & YE, 2010). QFD transforms user or market requirements into design requirements, component parts characteristics, process requirements, and production requirements, integrates customer ideas and needs into product design, systematically combines market-based customer demands (CR) with specific engineering properties of products (DR). And achieves matching of technical properties of products and customer needs in the market, which is conducive to the design and production of products that meet the needs of customers.

1.1.3 TRIZ and the Integrated Innovation Method

TRIZ (the Russian acronym for the theory, English acronym is Theory of Inventive Problem Solving, TIPS) is the knowledge-based, systematic approach to innovation. Developed in the former Soviet Union by Genrich S. Altshuller (1926-1998) and his school, colleagues after 50 years of research (Altshuller, 1996, 1999; Altshuller & Shulyak, 1998), TRIZ methods are drawn from analysis of the most innovative inventions in different industries, technologies, and fields of engineering.

Altshuller studied the methods for eliminating contradictions, proposed inventive principles for eliminating contradictions, and established a series of knowledge-based contradiction-eliminating inventive methods, including the types of resources, division of invention level, ideality level, 40 inventive principles, 39 engineering parameters, contradiction matrix, separation principle, substance-field analytical model, 76 standard solutions, knowledge effects base, inventive problem solving program ARIZ, etc..

At present, TRIZ has become a research focusing in the field of quality engineering abroad, especially in Europe and the United States (Maarten, 2011; Low, Lamvik, Walsh, & Myklebust, 2001). Some well-known large companies have begun to study and apply TRIZ to solve innovation problems in the production technology and non-technical areas (ZHENG, 2003; TAN, ZHANG, CHAO, & JIANG, 2005; YANG & SHAO, 2009; LUO & SHAO, 2012).

1.2 TRIZ Based Integrated Innovation Method

Due to the rapid development of economics, society, science and technology, TRIZ has to improve to meet the need of actual application. TRIZ developed only if absorbs the advantages of the other subjects' methods. The new integrated method is called integrated innovation method in this paper.

To solve different problems, TRIZ based integrated innovation method has the flowing characteristics. TRIZ problem solving approach flow chart with TRIZ integrated innovation tools is as shown in Figure 2. The integrated innovation tools has two parts. The left part is the TRIZ problem solving process, and the right part is the TRIZ based knowledge system. The TRIZ based knowledge system also has two different kind knowledge, the classical TRIZ knowledge and the other subjects knowledge. This two parts are integrated to form the knowledge system to provide the problem solving knowledge.

1.2.1 Problem Analysis

Each of the major tools of TRIZ can be used in a variety of stages of problem solving analysis. For simplicity, the tools of TRIZ will be explained briefly, and a correlation matrix will be proposed to identify the opportunities to use TRIZ to solve the specific problem.

There are many ways to organize the tools and techniques of TRIZ based integrated innovation methods. The flow chart is useful if understanding the integrated innovation methods, especially for the TRIZ systemic innovation knowledge, since it shows how the tools are related, as well as what they are. Figure 2 is a typical flow chart used for either a product design or process development problem with the TRIZ integrated innovation method.

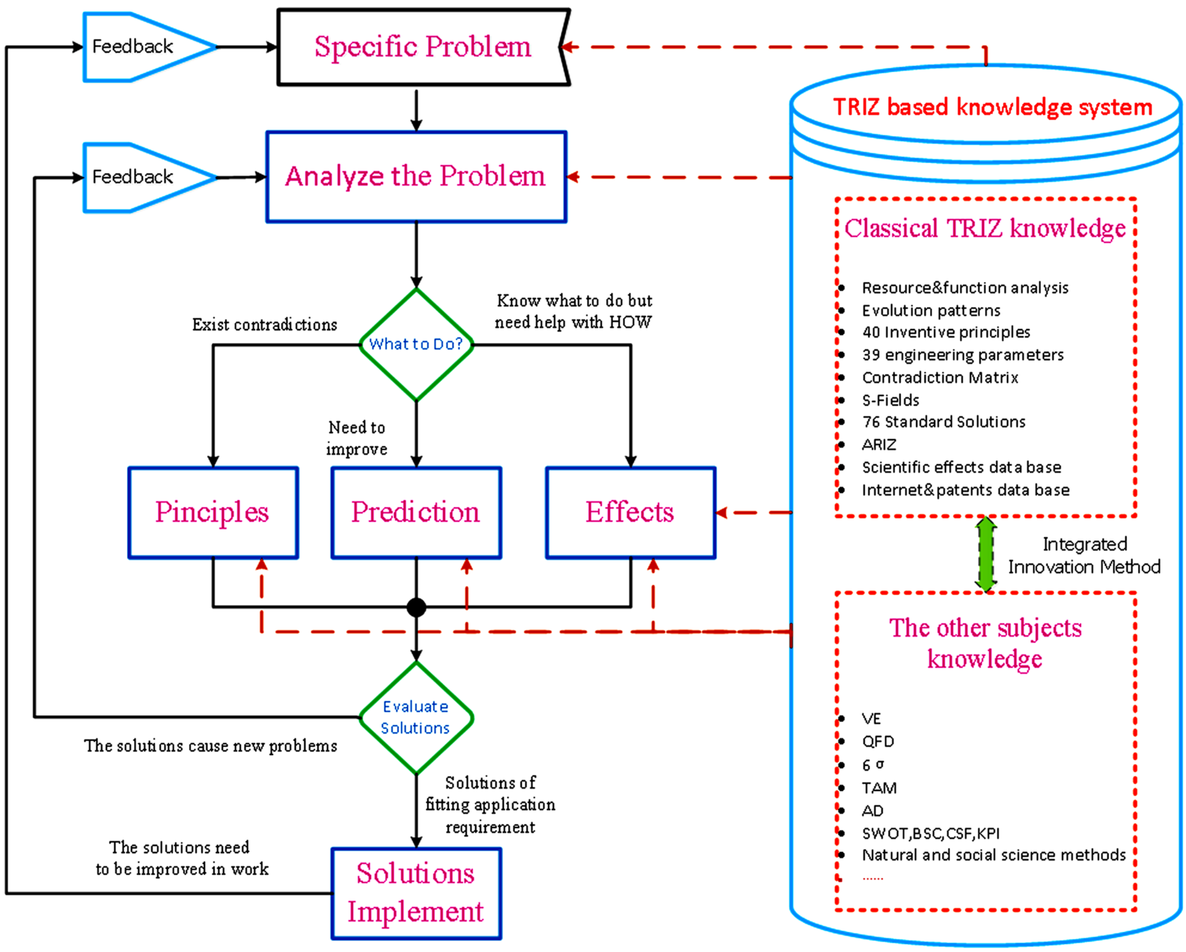


Figure 2
TRIZ Problem Solving Flow Chart with Triz Integrated Innovation Tools

The first stage of problem analysis tools shown on the flow chart are:

(1) **Functional Analysis.** Analyze the system, subsystems, and components in terms of the functions performed (not the technologies used). One new technique in TRIZ is "trimming" – examining each function to see if it is necessary. If it is, whether any other element of the system could perform the function. Breakthrough designs and reductions in cost and complexity are frequent results of functional analysis and trimming.

(2) **The User's Ideal Final Result.** Users as the customers' demanded quality. Express the situation in terms of why the innovation is needed, using technology-independent and implementation-independent language. Strategic breakthroughs frequently come from the insight gained at this step. Quality improvement opportunities can be identified finding what elements make the system non-ideal. The progress that a design makes from a starting point toward the ideal final result is called "ideality" and is defined using the value equation as

Definition 1 The ideality level of the system at a certain time t is $I(t)$. The sum of all harmful functions at a certain time t is H_y. The sum of all useful functions at a certain time t is $F(x)$. x represents the useful function variable. y represents the harmful function variable. $f_i(x)$ denotes the value of the i the useful function module. $h_j(y)$ denotes the value of the j the harmful function module. α_i denotes the impact factor (weight) of the i the useful function module. β_j denotes the weight of the j the harmful function module, on condition that the system contains m (number of modules) useful function modules and n (number of modules) harmful function modules, the ideality level $I(t)$ will be

$$I(t)=\frac{F(x)}{H(y)}=\frac{\sum_{i=1}^{m}\alpha_i f_i(x)}{\sum_{j=1}^{n}\beta_j h_j(y)}\left(m,n\in N; I(t),F(x),H(y)\in R^+,\ H(y)\neq 0\right) \quad (1)$$

Where $\alpha=\sum_{i=0}^{m}\alpha_i=1\,(m\in N)$, $\beta=\sum_{j=1}^{n}\beta_j=1\,(n\in N)$

In the formula (1), all functions and variables are non-negative, $H(y)\neq 0$, but $H(y)\rightarrow 0$. In the application environment, due to the degree of importance of various function modules may not be the same to the overall system, each useful function module $f_i(x)$ and harmful function module $h_j(y)$ have different levels of influence, which are represented by the weights α_i and β_j, $0\leq\alpha_i\leq 1$, $0\leq\beta_j\leq 1$.

Useful function module is a macroscopic concept, which can be useful functions, profits, performance indicators, success factors, etc. in the practical application; harmful function refers to all the factors that can bring about negative impacts to the system, such as the cost of product, degree of harmful effects, failure factors, product defect level, degree of environmental pollution, and potential loss. In this study, ideality level $I(t)$ index is used to measure the size of the innovation degree.

(3) **Resource Analysis.** Identification of the available things, energy sources, information, functions, and other elements that are in or near the system, that could be combined with the elements of the system to improve it. We often find that an awareness of the uses of resources in TRIZ changes the way that they conduct customer observation visits.

(4) **Locating the Zone of Conflict**. It is familiar to quality improvement researchers as "root cause analysis". Understanding the exact cause of the problem. The "zone" refers to the time and place where the problem occurs. A new tool, anticipatory failure determination (AFD) introduced by Kaplan, Zusman, and Zlotin, reverses the process, and guides the researcher to look for ways to cause failures, to increase understanding of how to prevent the failures.

1.2.2 Problem Solved

If the problem has been solved in the analysis phase, developers frequently proceed to implementation. If it has not been solved, or if alternate solutions are desired for maximum creativity, the data-based tools, Principles, Prediction, and Effects are used. In many TRIZ applications, all three of the data-based tools of TRIZ are used. The flow chart shows a decision indicating the choice of tools.

(1) **Principles**. It is also called resolution of contradictions. Technical contradictions are the classical engineering "trade-offs". The desired state cannot be reached because something else in the system prevents it. Physical Contradictions are situations where one object has contradictory, opposite requirements. TRIZ guides the developer to design principles that resolve the contradiction, once the contradiction is defined in terms of standard parameters.

(2) **Prediction**. It is also called Technology Forecasting. TRIZ identifies 8 patterns of technical evolution. Designs of systems, subsystems or components can be deliberately moved to the next higher stage within a particular pattern, once the pattern is identified. The 8 patterns are:

- Increased Ideality
- Stages of evolution
- Non-uniform development of system elements
- Increased dynamism and controllably
- Increasing complexity, then simplicity
- Matching and mismatching of parts
- Transition to micro level and use of fields
- Decreased human interaction (increased automation).

(3) **Effects**. Use scientific and engineering phenomenology and effects outside the discipline in which they were developed. Tools include data bases, science encyclopedias, and searches of the technical literature to find alternate ways to achieve the functions that are needed to solve the problem. Classical examples include the use of geometrical solutions to mechanical problems and use of biological solutions to chemical problems as well as use of common science from one area that is unknown in others. Beside the classical scientific effect debase, the problem solver make use of the other subjects knowledge to solve the contradictions, such as VE, QFD, TAM, AD, SWOT, BSC, etc..

1.2.3 Feedback and Implement

The last block in the flow chart is Evaluation of Solutions. Solutions are compared to the Ideal Final Result, to be sure that the improvements do advance the technology and meet the customers' needs. Multiple solutions may be combined to improve the overall solution using a Feature Transfer which is similar to Pugh concept selection and improvement. If the solutions cannot fit the application requirement, then it means that the solutions need to be improved in work, so the new problems caused must be analyzed in the first stage.

The flow chart shows that remaining problems are resolved by iterating the process. The advantage of TRIZ is that the iterations are very fast, and a great number of innovative ideas are developed at each stage.

The general problem solving process of TRIZ based integrated innovation method can be used whenever the product or process developer has inventive problems, according to the different needs.

1.3 Comparative Analysis of Characteristics of TAM, QFD, and TRIZ

1.3.1 Analysis of Development Stage Based on Product Life Cycle

In terms of the TRIZ technological system evolution principle, the evolutionary process of product is divided into four stages: Infancy stage, growth stage, maturity stage, and decline stage, as shown by points 1, 2, 3, 4 in Figure 3(a). Technological system evolution theory can provide specific and scientific guidance for development of products of enterprises, and the evolution patterns, evolution laws, evolution paths, and application modes.

A system in the technological system evolution theory enable enterprises to have clear objectives at all stages of product development. Technological improvements within the same generation products are continuous innovations (also called sustainable innovation), and innovations across two different generations of products are disruptive innovations.

TRIZ technological system evolution theory-based product development process generally goes through five stages, as shown in Figure 3(b).

(1) **Basic survey**. Basic survey stage consists of competitive product analysis, domain analysis, product user positioning analysis, and product feature positioning analysis. Through the basic analysis, detailed product and market analysis report is formed, and detailed user demand is obtained.

(2) **R & D design**. Starting by product functional logic, and combined with user demand in the preliminary product survey. R & D design stage designs conceptual model, and forms the basic framework of product design including design documents such as functional structure diagram, scenario analysis, interaction process analysis, subsystem schematic diagram, and process flow diagram, providing comprehensive management and technical documentation for production or trial production of products.

(3) **Manufacturing**. Production department or enterprise draws up specific production process flow, manufactures and designs products that meet the requirements of technical specification based on the preliminary design documents. In this condition, technology department provides technical guidance on production process, quality management department is responsible for product quality supervision, and production workshop is responsible for specific trial production, production, assembly and commissioning of products.

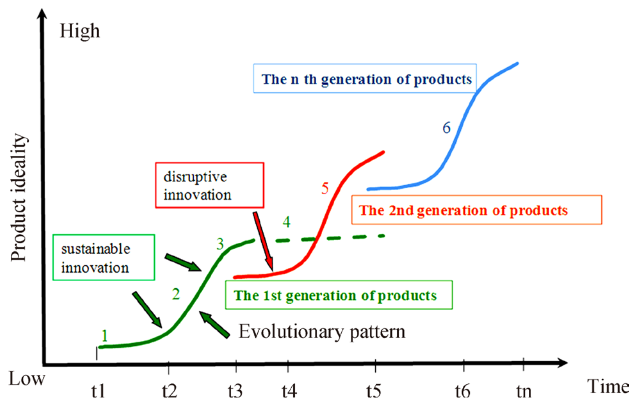
(4) **Marketing**. Before the launch of the product in the market, preliminary market promotion work is carried out according to the expected product features and market forecasts. Then a full range of marketing, customer relationship management, and after-sales service are carried out.

(5) **Customer use**. No matter how perfect the product design is, it has flaws and shortcomings. Problems can only be continuously found during the using of products by users, the manufacturer obtains information on product improvements and market share from the customer use process.

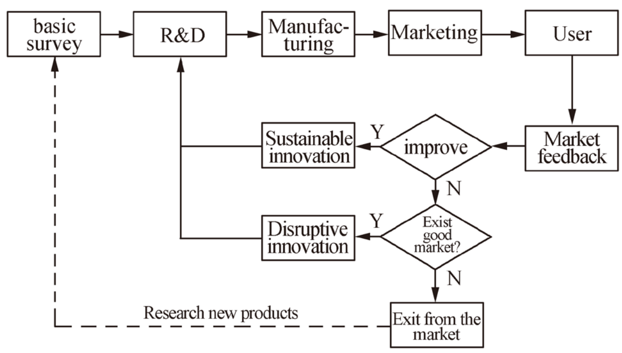
(6) **Market feedback**. Market feedback information is continuously obtained from the customer use process, which is sent to the marketing department to provide a basis for the further promotion of the product. Next step of the product development process is determined based on user feedback on product features, price, quality, etc..

(7) **Sustainable innovation – the improvement of products**. Whether products need to be improved is analyzed based on market feedback, if product improvement is needed, such partial refinement and improvement on product belong to sustainable innovation, new user needs are provided to the R & D department to guide the improved design of products.

(8) **Disruptive innovation – the development of new products**. Under the conditions that the products have large market potential, if users' needs cannot be met by improving product performance or partially refining some functions, re-design and development of new products are required to upgrade the products. R & D department and marketing department will fulfill the new user needs, and guide the development and design of products together. The development of new product on the basis of the original product is a disruptive innovation.



(a) Technological Evolution Path of Products



(b) Product Development Flow

Figure 3
Product Development Flow Diagram Based on Product Life Cycle

(9) **No user needs**. The product exits from the market. In case the product has neither improvement needs nor market prospects, it indicates that the product can no longer meet user demands, and that users have no intention to use the product, decision-making departments should stop the R & D and production of such product. At this time, research and development of completely different product is needed to replace the original product.

1.3.2 Comparative Analysis of TAM, QFD, and TRIZ Innovation Methods

Three innovation methods present different advantages in different stages of product development; Figure 4 shows the comparison of advantages of TAM, QFD, and TRIZ in different implementation stages of product processes.

(1) **Analysis of advantages of TAM**. It can be seen from Figure 4 that TAM is mainly an empirical research tool aimed at customers and market, through empirical research, the extent of demand for product (usefulness) by users and convenience of product (ease of use) can be estimated, and possible attitude toward using of product as well as using intention by users can be studied or predicted. Thereby determining the possible market prospects of the product, and providing accurate market information for the initial design, improvement, and upgrading of product, TAM mainly reflects its unique methodological advantages in the basic survey and market feedback stages.

(2) **Analysis of advantages of QFD**. QFD is a bridge connecting users' demands with technical features of product, which links the users' demands to the quantitative product technical features, providing a scientific basis for decision making of subsequent R & D design and manufacturing, and achieves matching of user demands and product technical performance. Products which meet the needs of users are produced through guaranteeing product technical performance and quality in the manufacturing process. QFD has more unique advantages in the R & D and manufacturing stages of product.

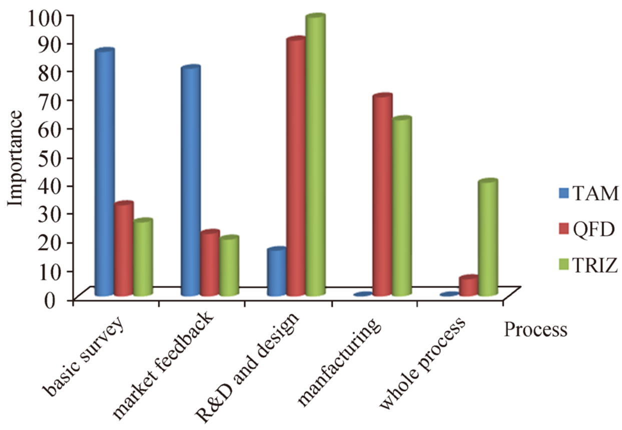


Figure 4
Comparison of Advantages Among TAM, QFD, and TRIZ

(3) **Analysis of advantages of TRIZ**. TRIZ is a theory system based on the inventive and innovative method. TRIZ innovative ideas can be embodied in each stage of product development. More advantageous points in product implementation process lie in: First, technology survey and market feedback stages, according to the product evolution theory, consumer trend and intention toward using product, trend analysis on possible demand for next-generation product, and ideal product model are simulated or surveyed and researched; second, R & D design and manufacturing stages, according to the system analysis, substance-field model analysis, contradiction analysis, resource analysis, ideality level, 40 inventive principles, etc., conceptual design of product is achieved, evolution trends of product are predicted, and product failure is detected, providing contradiction problem solving ideas for management, technology, marketing, and customer application fields, and providing methodological guidance for the entire process of product innovation.

2. TAM, QFD, AND TRIZ INTEGRATED PRODUCT INNOVATION PROCESS

According to the advantages of TAM, QFD, and TRIZ in different stages of enterprise's entire product manufacturing process, the three innovation methods are integrated to get the new integrated product innovation process architecture as shown in Figure 5. Solid black boxes represent critical stages of product development; solid black arrows represent the order of product development process; red dotted boxes represent the domain of innovation method, flowcharts and display contents within red boxes represent main processes of problem resolution by innovation method; and orange dotted arrows represent the problem solving logical relationship between innovation method domains and relevant production process stages.

2.1 Application of TAM

TAM is a tool for the study of user demands and intentional behaviors in the design of information systems. The purpose of applying TAM to basic survey research and market user feedback in new product development process of enterprises is to better understand customer and market demands. For newly developed products, possible user demand conditions for new products need to be understood and predicted; for already launched products, user intentions to use the product, attitudes toward using should be acquired, and defects and features to be improved and market share situations should be analyzed to avoid non-conformity of design of services and products to the practical application. TAM obtains whether users think the product is useful, easy to use, whether to choose the product, how is the using effect, etc.. Through the studies of product system design characteristics, user characteristics (including cognitive style and other personality characteristics), task characteristics, nature of the development or implementation process, policy influences, organizational structures and market development strategies of companies, internal beliefs, attitudes, and intentions of users during the application of product, differences between individuals, environmental constraints, controllable interference factors, etc., and then studies other customer demands by other survey methods, providing user needs related information for the application of QFD innovation method in the next stage.

2.2 Application of QFD in Integrated Innovation Process

Information on market and customer demands for product is obtained through preliminary TAM and other market survey methods; QFD reflects customer needs in the customer requirements matrix to provide relevant information on production, management and technology for the R & D, design and manufacturing. (1) R & D design stage. The main objective is to identify key product characteristics, transform key product characteristics into component characteristics, determine performance of parts, and determine the details and each component necessary for the production of product or service. (2) Manufacturing stage. Key component characteristics in the previous stage are transformed into engineering characteristics, then a matrix that illustrates the processes required for the production of product is developed, and then process characteristics in the process steps are associated with market characteristics, so that the processes appeared in this stage can best fulfill specific requirements of customers for products, the key process characteristics are transformed into production characteristics. In the four processes of QFD, five standard split units are included, transformation sequence is: customer demands – product characteristics – component characteristics – process characteristics – production characteristics, in each process, "what to do" in the process is analyzed, which is then transformed into a more detailed analytical unit "how to do". Entire QFD control process is a coherent whole, which is expanded in more detail in the production based on different departments, different products and application requirements and according to actual demands.

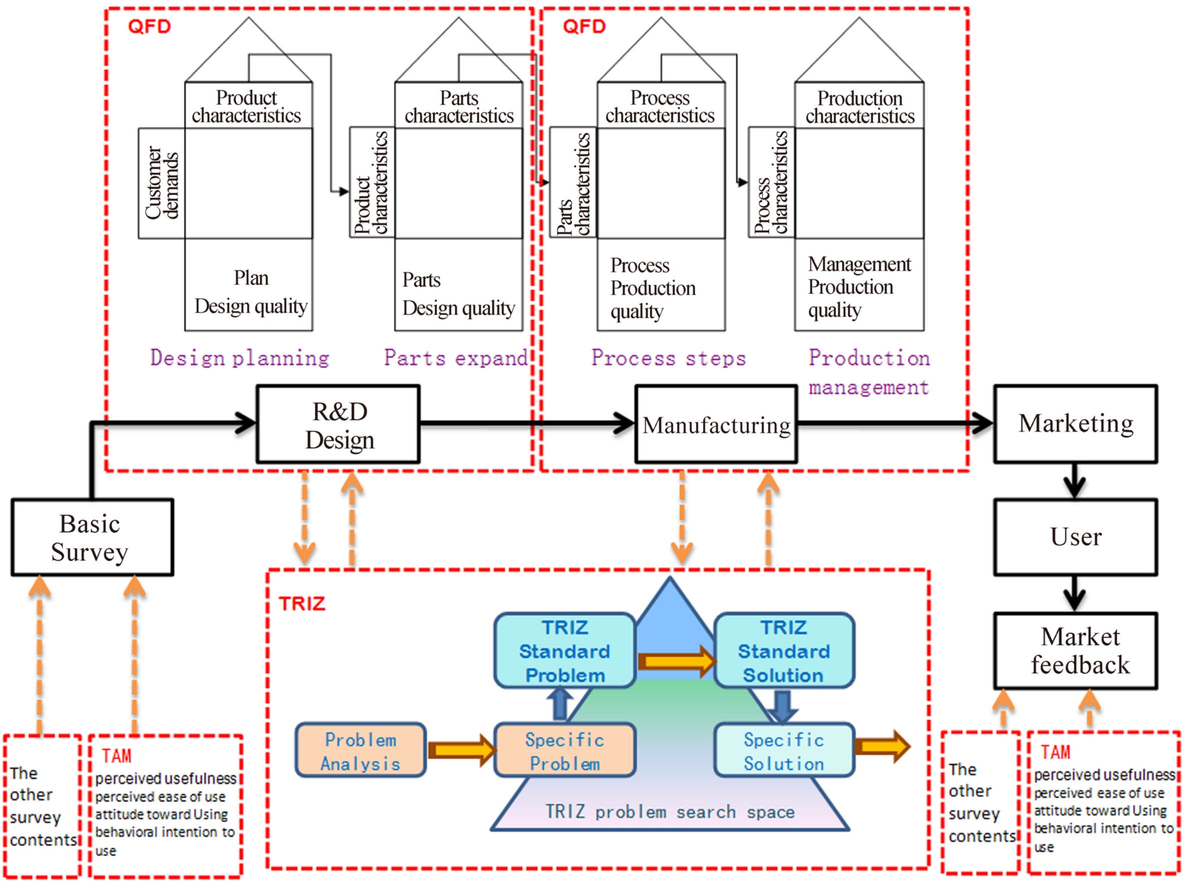


Figure 5
TAM, QFD, and TRIZ Integrated Product Innovation Process Diagram

2.3 Application of TRIZ Theory in Integrated Innovation Process

QFD merely establishes a necessary connection between demand problems described by the system in previous stage and key indicators need to be addressed in present stage, and selects optimal alternative by means of quantity matrix. But it does not systematically provide ideas about why to solve the problems this way and how to solve the technological and management problems. Because how to use more ideal systematic innovation method to solve these problems require more sophisticated professional knowledge and interdisciplinary knowledge, TRIZ exactly compensates for the innovative problem solving contradictions in the product design and manufacturing. There exist contradictory problems or engineering problems which need to be addressed in the R & D design and manufacturing stages, in case that the problem can not be solved with direct professional knowledge, TRIZ innovation method can also play a role in product evolution, resolution of management problems and technological contradictions, pre-detection of product failure problems, etc.. The idea is: Encounter of contradictory problems in R & D, design, manufacturing stages→analysis of contradictory problems→transformation of contradictory problems into specific problems→transformation into standard TRIZ problems→obtaining of standard answers→obtaining of specific answers→scheme evaluation→production and application, TRIZ innovation methodology also has an important role in guiding innovations in non-technical fields such as marketing, after-sales service, and corporate management.

3. APPLICATION EXAMPLE OF INTEGRATED INNOVATION METHOD IN THE DESIGN OF NEW WALL MATERIALS

New wall materials manufactured by Guizhou Long Life Forestry Group are used as an example to illustrate the application of TAM, QFD and TRIZ integrated innovation method in this research, development and production of new wall materials.

3.1 Introduction of New Wall Materials

New wall materials refer to the materials which use coal ash, coal gangue, stone dust and other waste as the main raw material, and have energy saving, land conservation, waste utilization, heat preservation, thermal insulation, light weight, high strength, seismic resistance, and environmental protection performances. Originally, new wall material is a general term, relative to traditional wall materials solid clay bricks, those various types of wall materials which have energy saving, soil saving, waste utilizing, and multifunctional features, conducive to environmental protection, in line with the requirements of sustainable development, and can significantly improve the building function are collectively referred to as the new wall materials (CHAO, 2006).

3.2 Analysis of New Wall Material User Needs Based on TAM Method

The technology acceptance model of new wall materials is as shown in Figure 6, in order to more completely identify the external variables that reflect consumer intentions to use new wall materials, through user needs survey, and by reference to the opinions of experts in related fields, the external variables which may affect consumer's intentions toward using are summarized.

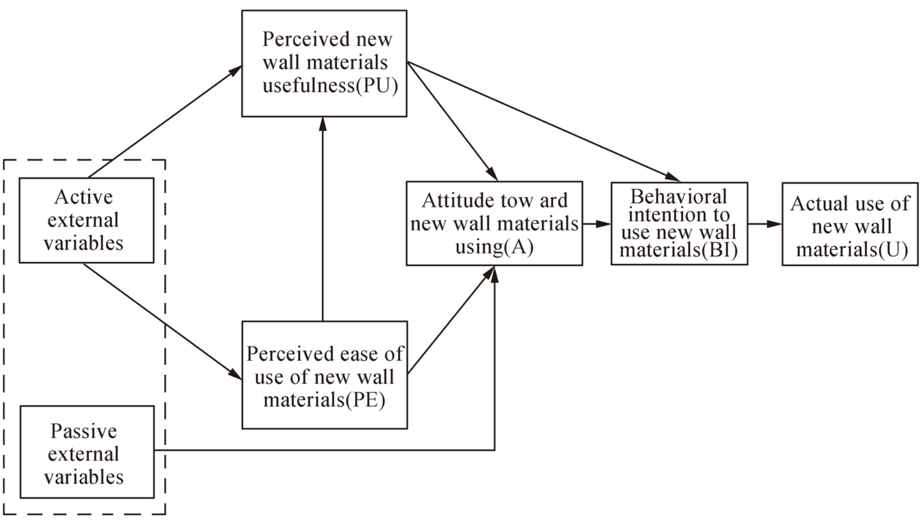


Figure 6
Technology Acceptance Model of New Wall Materials

In the technology acceptance model of new wall materials, perceived usefulness refers to the subjective cognition of consumers on expected degree of improvement of building quality and work efficiency by new wall materials; perceived ease of use refers to the degree of easy-to-use of new wall materials in application, which can be measured through the appropriate variables. Variables affecting the perceived usefulness include attractiveness of product quality features, integrity of product, manufacturer's quality of service, development prospects of new wall materials, manufacturer's commitment to consumers, value and impact of some special performance of new wall materials on customer demand, etc.. Variables affecting the perceived ease of use: technical background of product, cultural background of enterprise, etc..

In the TAM, the user may be influenced by some external variables outside of own characteristics, such as price factors, emotional factors, herd mentality, and additional cost for use of new wall materials. These factors are passive external variables, which affect the user's attitudes towards using new wall materials.

User needs are obtained through the TAM method as shown in Table 1, where 5 indicates the highest importance degree, and 0 indicates the lowest, customers have the highest requirements on safety and quality of products, and have no special requirements on anti-seismic performances.

Table 1
User Needs Based on TAM Method

No.	Customer and market needs	Degree of importance	Needs explanation
1	Safe and reliable, quality assurance	5	Assurance of safety and quality by comprehensive technical performance of product, such as strength, residue blending ratio, pore ratio, thermal resistance, sound insulation effect, fire resistance performance, waterproof performance, anti-corrosion performance, etc..
2	Good product usability	4	Easy installation, dismantling, transportation and use, convenient for construction, light weight, save construction costs.
3	Willingness to use high-tech products	4	New materials, study the user attitude toward using of new wall materials through the possible user attitude toward using survey research
4	Aesthetic, environmental friendly, no secondary pollution	4	Relative to traditional building materials, the users have more needs in choosing more beautiful wall materials, the materials should be environmental friendly, with no secondary pollution.
5	Good sound insulation, waterproofness, and fire resistance	4	Technical performance of new wall materials should meet soundproof, fireproof, and waterproof performance requirements.
6	Strong anti-seismic capability	3	Performance indices of new wall materials should meet quakeproof and anti-seismic performance requirements, and should be ensured by comprehensive technical performance of product.

1) Safe and reliable, quality assurance. The most important need for new wall materials is safety, and safety must be reflected through reliable technical performance and good product quality, which is expressed in the aspects such as strength, residue blending ratio, pore ratio, thermal resistance, sound insulation effect, fire resistance performance, waterproof performance, and anti-corrosion performance.

2) Good product usability. Easy installation, dismantling, and use, labor saving, relative to traditional materials, new wall materials are light weighted, and save labor and cost in the construction.

3) Willingness to use high-tech products. User psychology surveys found that, if it is a high-tech product, users will try it out in the wait-and-see approach, in the actual trial use, they will continue to use the product if overall performance exceeds expected requirements.

4) Aesthetic, environmentally friendly, no secondary pollution. While meeting the basic safety performance and quality requirements, new wall materials also have good waterproof performance, anticorrosion property, and decorative finishing features, with no secondary pollution during the use, which are environmental friendly and energy saving.

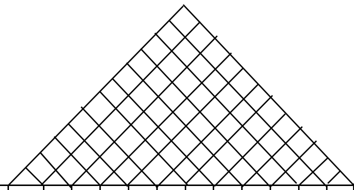
5) Good sound insulation, waterproofness, and fire resistance. The application of new building facilities require the sound insulation of housing structure to achieve a certain standard, require good waterproof and damp-proof performance, and require the fire resistance performance to meet the requirements.

6) Strong anti-seismic capability. Since the 5.12 Wenchuan Earthquake in 2008, government has improved the anti-seismic performance requirements standards for residential buildings, and set higher requirements for the anti-seismic capability of new wall materials.

3.3 Product Design Analysis Based on QFD

Based on the customer and market demands, QFD diagram was obtained as shown in Figure 7, the product characteristics corresponding to the specific needs of users are:

1) Customer and market demands. Customer and market needs, in the order of the degree of importance, are: safe and reliable product, quality assurance; good product usability; willingness to use high-tech products; aesthetic, environmental friendly, no secondary pollution; good sound insulation, water and fire resistance performance; strong anti-seismic capability.



Importance		Correlation	
5	High	9	Strong
4	High-	3	medium
3	medium	1	weak
2	medium-		no
1	low		
	no		

Quality Function Expansion	Importance degree Ki	A bulk density(kg/m3)	B bending failure load	C compressive strength(Mpa)	D impact resistance(sandbag/times)	E softening coefficient	F moisture content	G dry shrinkage ratio	H thermal conductivity	I fire endurance	J sound reduction index	K environmental protection	L easy exterior installation	Market competitiveness analysis: Guangzhou ** Building Materials Co.	Market competitiveness analysis: Guiyang ** building materials company	Quality Planning: The level of Long Life Company	Target	Increasing rate	Selling point	Absolute weight	Quality requirements weight
Sum of Correlation																					
Direction of improvement																					
Customer and market demands: 1 safe, quality assurance	5	3	9	9	9	9	9	9	9	9	9	9	9	3	2	4.0	5.0	1.25	1.5	9.4	0.31
2 good product usability	4	9				3	9	9				3	9	3	2	4.0	4.0	1.00		4.0	0.13
3 use high-tech products	4		9	9	9	9	3		9	9	9	9		3	5	5.0	5.0	1.00		4.0	0.13
4 no secondary pollution	4	9						3			3	3		3	3	4.0	4.0	1.00		4.0	0.13
5 sound insulation,etc	4					9	9	9	3	9				3	3	4.0	4.0	1.00		4.0	0.13
6 strong anti-seismic capability	3		9	9	9	3		3			9			3	2	3.0	4.0	1.33	1.2	4.8	0.16
engineering measures importance		36	57	15	5	81	27	12	12	27	27	27	4	0.60	0.57	0.81	0.88	market competitive Mi			

Technological competitiveness	A	B	C	D	E	F	G	H	I	J	K	L	Technology competitiveness Ti
Traditional wall materials	1	3	3	2	2	3	3	2	2	3	1	1	0.453
Energy saving wall products of Long Life Group	4	4	4	4	5	5	5	4	5	4	5	5	0.904
The domestic industry	3	3	4	3	4	5	4	3	4	3	3	4	0.725
the same industry of Guiyang	4	3	4	3	4	4	4	5	5	3	3	3	0.751
quality factors importance degree: Absolutely important degree	87	108	108	108	138	129	138	93	117	120	105	81	
Relative importance degree	6.5%	8.1%	8.1%	8.1%	10.4%	9.7%	10.4%	7.0%	8.8%	9.0%	7.9%	6.1%	

Figure 7
QFD Diagram of Long Life Energy-Saving Wall Products Production

2) Product characteristics. Product characteristics mainly include the following aspects: Bulk density (kg/m^3), bending failure load (panel weight multiples), compressive strength (Mpa), impact resistance (standard sandbag/times), softening coefficient, moisture content, dry shrinkage ratio, thermal conductivity, fire endurance, sound reduction index, environmental protection, easy exterior installation.

3) Technological competitiveness analysis. The inter-peer competitiveness analysis of traditional wall materials and Long Life company's energy-saving wall products in China finds that Long Life company's products have the highest competitiveness coefficient, which is 0.905, the competitiveness coefficient of traditional wall materials is 0.453. It is thus clear that the tradition wall materials are outdated in respect of technological advancement; the products manufactured by another building materials company in Guiyang, Guizhou also have relatively strong market competitiveness, with competitiveness coefficient of 0.726. Main competitive advantage is reflected in the moisture content of the material, where moisture content is relatively low. Technologically, the products of Guiyang companies are the technology-followers of Long Life's products, which are the biggest competitors of Long Life's products.

4) Assessment of market competitiveness. From the perspective of meeting customer needs and market demands, all the properties of Long Life company's products are favored by users, which have strong market competitiveness, Guiyang company's market

competitiveness is 0.81, Guiyang ** building materials company is 0.57, Guangzhou ** building materials company has a market competitiveness coefficient of 0.60. Guiyang ** company promotes high-tech products, but have poor user satisfaction in terms of product safety, convenience, environmental protection, sound insulation, waterproofness, and anti-seismic capability, our company's products have relatively high competitiveness in the market.

5) Analysis of technical problems to be solved. Viewing from the user needs meeting evaluation parameters, the most important are the softening coefficient, moisture content, and drying shrinkage, once wall materials are affected with damp, they will easily become softened, compressive strength and other properties become poor, affecting the quality and safety; the next important are fire resistance, sound reduction, compressive strength (Mpa), etc., the least important are ease of installation and thermal conductivity, because these contradictions can be overcome and prevented during the use, which are not the performance indices must be met by the products.

Technical parameters required by the above customer needs are solved, after comprehensive assessment, products are selected and designed in accordance with the principle of ideal degree maximization, in order to meet the comprehensive performance indices of new wall materials.

3.4 Application Analysis of TRIZ Innovation Method in New Wall Material Design

3.4.1 Main Contradictions Presented in the Design and Production of New Wall Materials

In accordance with the requirements for product performance after QFD deployment, main contradictory problems manifested in the design and production of new wall materials are:

1) The higher the requirements for strength, the larger the volume of wall materials. Technical contradiction: High strength, small volume.

Table 2
Contradictory Problem Solutions in Wall Material Design

Contradictory problems	Types and patterns of contradiction	TRIZ theory solutions	Engineering application measures
Strength	Technical contradiction: high strength, small volume.	1. Substance-field model, introduce additional substance S, to increase the strength of field F; 2. Inventive principle 30, flexible shell or thin film principle, use flexible shells and thin films instead of traditional structure.	Wall core consists of polystyrene particles + high-alumina cement + nano vacuum agent + a variety of functional additives, to increase strength, and reduce volume.
Residue blending ratio	Technical contradiction: high residue blending ratio, low strength.	Inventive principle 5, merging principle. Merge similar or adjacent objects or operations on the space.	Use two wall boards (high strength wall panel) to clamp the wall body, after solidification, comprehensive strength of filler material and exterior panel improves.
Pore ratio	Technical contradiction: high pore ratio, reduced strength.	Inventive principle 31, porous material principle. If an object is already porous, use these pores to introduce a useful substance or function.	Add polystyrene particles into the wall core, after mixed with cement and nano vacuum agent, strength and toughness increase.
Thermal resistance	Physical contradiction: large volume, small volume.	Inventive principle 39, inert environment principle. Complete the process in vacuo.	Add polystyrene particles and nano vacuum agent into wall core, to increase the vacuum degree, reduce thermal conductivity, and increase thermal resistance.
Sound insulation	Technical contradiction: thin wall, good sound insulation.	Inventive principle 31, porous material principle. Inventive principle 39, inert environment principle.	After polystyrene particles and nano vacuum agent are added into wall core, transmission of sound is prevented, and sound insulation performance increases.
Fire resistance	Technical contradiction: poor thermal conductivity, good strength, incombustibility.	Inventive principle 31, porous material principle. Inventive principle 39, inert environment principle. Inventive principle 40, composite materials, change from uniform material to composite material.	Add polystyrene particles and nano vacuum agent, mix with high-alumina cement and a variety of functional additives, to form composite materials.
Waterproofness	Technical contradiction: low water absorption, high strength.	Inventive principle 31, porous material principle. Inventive principle 39, inert environment principle. Inventive principle 40, composite materials.	Add polystyrene particles and nano vacuum agent, mix with high-alumina cement and a variety of functional additives, to form composite materials.
Installation	Technical contradiction: quick installation, high efficiency, low cost.	Inventive principle 10, preliminary action principle. Complete in advance part or all of the actions or functions. Inventive principle 40, composite materials.	Pre-make wall materials into boards with certain specification, design V-shaped slot, to facilitate quick and convenient installation and construction.

To be continued

Continued

Contradictory problems	Types and patterns of contradiction	TRIZ theory solutions	Engineering application measures
Environmental protection	Technical contradiction: pollution-free production, no construction waste, no secondary pollution.	Inventive principle 22, blessing in disguise principle, use harmful factors to achieve a positive effect. Inventive principle 15, dynamics principle. Divide an object into several parts capable of movement relative to each other.	Use cinder and construction waste as raw materials, to change discarded hazardous materials into beneficial materials; no sewage disposal during production, no industrial production pollution; design wall materials into V-shaped slot, to facilitate dismantling.

2) In order to save the cost and protect the environment, under the premise of assuring using function, waste residue utilization rate must be raised as high as possible, but the higher the residue blending ratio, the lower the costs, the better the saving of resources, and the lower the strength. Technical contradiction: High residue blending ratio, low strength.

3) High pore ratio can reduce the building weight, improve anti-seismic performance of buildings, improve the wall heat insulation, facilitate transportation and construction, high pore ratio means small volume, light weight, and good thermal insulation, but high pore ratio lowers strength. Technical contradiction: High pore ratio, reduced strength.

4) The thicker the traditional wall, the better the sound insulation effect, but volume and mass will increase, and cost is high. New wall materials are required to be light weight, and have good sound insulation effect. Technical contradiction: Thin wall, good sound insulation.

5) As the main structural material of buildings, combustibility of blocks meets or exceeds the requirements of national standard GB8624-1997 “Classification of Combustibility of Building Materials”, which must be incombustible or flame retardant materials. Its fire endurance must meet the specified construction requirements. In case of combustion, it must not produce suffocating toxic gases. High fire endurance, incombustible or flame retardant, does not produce toxic gases at high temperatures. Technical contradiction: Poor thermal conductivity, good strength, incombustibility.

6) As the main structural material, blocks must be hydraulic materials, with very low water absorption, very high softening coefficient, and impermeability index meeting a certain threshold. Only by waterproofing, can the water and frost resistance of buildings be ensured. If the wall has high strength, it will not be deformed after contacting with water, and will have low water absorption. Technical contradiction: Low water absorption, high strength.

7) As block (brick) wall materials, if secondary treatment of finishing can be avoided, a lot of post decoration costs can be saved, and one-time work can be achieved. If wall surface finishing does not need secondary treatment, costs can be saved. Technical contradiction: Good decorative finishing, low cost.

8) Easy installation, dismantling, transportation, reduction of labor and logistics costs. New type walls require quick installation, high efficiency, easy installation, convenient dismantling and transportation. Technical contradiction: Quick installation, high efficiency, low cost.

9) No secondary pollution, zero emissions, and no construction waste in the production process. Pollution-free production, less construction waste. Technical contradiction: Pollution-free production, no construction waste, no secondary pollution.

3.4.2 Contradictory Problem Solutions with the Use of TRIZ

According to the solving ideas of TRIZ innovation process, a few typical contradictory solutions are cited as shown in Table 2. Typical problems include:

1) Strength. Technical contradiction: High strength, small volume. Solution: Use the substance-field model, introduce additional high polymer materials, and improve the strength of new wall materials to reduce the volume.

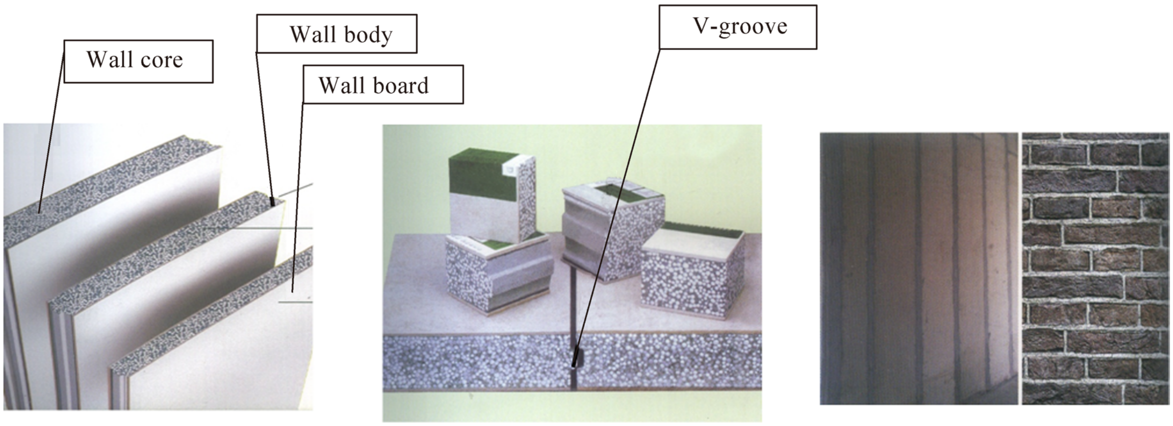
2) Residue blending ratio. Technical contradiction: High residue blending ratio, low strength. Solution: Inventive principle 5, merging principle, use two wall boards (high-strength wall panel) to clamp the walls, although the strength of filler material is low, after solidification, the comprehensive strength is improved.

3) High pore ratio. Technical contradiction: High pore ratio, reduced strength. Solution: Inventive principle 30, flexible shells or thin film principle. Make the pores ductile by adding polystyrene particles to the wall core, while achieving fireproof and soundproof effects. Inventive principle 31, porous material principle is also used here.

4) Pollution-free use, less construction waste. Technical contradiction: Pollution-free production, no construction waste, no secondary pollution. Solution: Inventive principle 22, blessing in disguise principle, use the waste cinder, etc. to mix materials such as high-alumina cement and vacuum agents; inventive principle 40, composite material principle, combine a variety of different materials closely together to form a new material. Composition of various materials, compose polystyrene particles + high-alumina cement + nano vacuum agent + a variety of functional additives to form wall panel materials.

3.5 Actual Product Solutions

The structure of new wall material products manufactured by Guizhou Long Life Forestry Group Co., Ltd. is as shown in Figure 6; the wall materials consist of three parts, the wall core, wall body, and wall panel. Of which wall core is composed of polystyrene particles + high-alumina cement + nano vacuum agent + a variety of functional additives, wall panel is composed of ACC high pressure cement fiberboard, and V-shaped slot is pre-opened in the wall body to facilitate easy assembly and disassembly, construction is convenient, fast, and pollution-free.



(a) New energy-saving wallboard (b) New energy-saving wall structure (c) New wall materials and traditional brick wall

Figure 6
New Energy-Saving Wall Material Products

Table 3 shows the application of main innovation methods in actual product parts. Wall core uses substance-field model to increase the strength of the field F, uses composite material consisting of polystyrene particles + aluminous cement + nano vacuum agent + a variety of functional additives to form porous structure, where inventive principle 30 and 31 are applies; wall body uses the inventive principle 10 to pre-open a concave-convex structured V-shaped slot, during use, a small amount of mortar is applied at the slot joint to caulk the joint, installation and dismantling is convenient, and can be used multiple times; due to the higher strength of two wall boards, clamping of the wall body not only increases overall strength, but also improves the local quality through the inventive principle 5 merging principle; entire wall material uses waste materials such as fly ash, coal gangue, and construction waste as the raw materials, and applies the inventive principle 22 to turn the harmful waste materials into beneficial; during the production, there is no wastewater discharge, no soot emissions, no harmful toxic additives, and energy consumption is less, production and use are energy-efficient and environmental friendly.

Table 3
Application of Innovation Methods in Design of Parts of New Wall Material Products

Part	Materials and processing	Application of TRIZ innovation method
Wall core	Consists of polystyrene particles + high-alumina cement + nano vacuum agent + a variety of functional additives, porous	1. Substance-field model, increase field F to increase strength 2. Inventive principle 30, flexible shell or thin film principle, use flexible shells and thin films instead of traditional structure 3. Inventive principle 31, porous material principle
Wall body	Open V-shaped slot, easy to install	Inventive principle 10, preliminary action principle. Complete in advance part or all of the actions or functions.
Wall board	Clamp the wall body using two wall boards (relatively high strength)	Inventive principle 5, merging principle. Merge the similar or adjacent objects or operations on the space.

Energy-saving wall materials has the following advantages: first, fast construction, low operating intensity, clean and sanitary; second, simple process, small workload, low work intensity in the wall material filling operation; third, in the reconstruction and secondary decoration, the materials can be laid out at will not affected by the position of beam column in the main building structure, easy adjustment of construction scheme.

CONCLUSION

According to the characteristics in different stages of product development, a TAM, QFD, and TRIZ-based integrated innovation method is proposed, which is applied to the R & D and production of new wall materials.

(1) The advantages of TAM in study of customer needs are utilized to provide accurate information on

customer needs and market demands for QFD.

(2) The advantages of QFD in program planning and quality control in R & D design and manufacturing stages are utilized to assist the system in identifying the most important product performance indices and contradictory problems, then resolving them by TRIZ innovation method, three innovation approaches are integrated and applied to the R & D of new wall materials, which is conducive to the application of TAM, QFD, and TRIZ in the field.

The TRIZ-based integrated innovation method proposed in this paper focuses on the identification and resolution of contradictory problems in customer demand and quality control in the product design process. And the resolution of other management contradictory problems in the production and operation process, relevant researches where other innovation methods are combined are needed, which will be explored by the author more in depth in the next stage.

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