



The Dry and Light Interactive Composite System (DALICS) by Assembled Steel in Vietnam's Current Construction Industry

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Abstract: Since the colonial era, at the beginning of the 20th century, a totally new material started to be used in Vietnam by the French, which is assembled steel. After one hundred years, it occupies a certain position in the field of architecture and construction and development to be the dry and light interactive composite system. In this research, the author especially focuses on assembled steel of the Dry and light interactive composite system (DALICS) method. The aim of this research was to analyze and evaluate the status of the DALICS nowadays in Vietnam, so that predict the orientation of its development in the future. The research method is collect the data, interviewing the stakeholders, and the practical experiment through reality DALICS construction to prove its technologies and benefit. The result is connected with social context to contribute an overall view of Vietnam's current building industry, therefore, predicts the direction of the assembled steel frame and the DALICS method in the Vietnam building industry in the future.

Keywords: The DALICS, assembled steel, dry construction, composte system, building industry

1. Introduction

1.1 Brief Introduction about the DALICS Method

Beginning to be used in construction in the early 19th century, assembled steel is a flexible construction method and is widely used today. Buildings using assembled steel in the world are very diverse and of different sizes, from civil works such as houses, hotels, restaurants to public works such as schools, airports, stadium.

And *Dry and light interactive composite system* is a revolution of this construction method, which organized the dry construction method currently uses mainly assembled frame structures (usually wood or steel) and panel covers (wood, plaster, cement board, and many other materials) (Huy, 2019). In this research, the author only concentrates on the assembled steel frame of this method. As the name, the DALICS is the system of many assembled elements, which have lightweight and pre-produced in the factory, mount together by flexible joints, and do not need to use water during the construction period (Dubosc and Huy, 2014). In the case of Vietnam, the DALICS is the revolution from the steel frame structure and brick wall model to steel frame structure and panel wall model, completely without using water. The DALICS construction method has many significant advantages such as less effect on the environment, saving construction time and cost, good fireproof, heat-noise insulation, and flexible architectural design.



Fig. 1 - Advantages of the DALICS method (Source: Author)

Firstly, to compared concrete and steel frame structure, the DALICS construction technology which included assembled components has improved labor health and neighborhood environment by cutting down the noise, pollution on the construction site, and giving eco-friendly jobs. According to Table 1 -Effects of constructing structures on the environment, the use of steel structures has less impact on the environment than reinforced concrete structures, the contribution to climate change is 25% as a half when compared with concrete reinforcement. Especially, steel frames are approximately 100% recyclable while preserving their physical and chemical properties, so resource extraction is 14% (highly reusable) while reinforced concrete is higher than 6 times, 93% (almost impossible to reuse). Furthermore, the development of steelmaking technology today helps to improve greenhouse gas emissions from steelmaking is 45% lower than 40 years ago. Water consumption in the steelmaking process has decreased by 70 gallons per ton of steel. In addition, the gas from the kiln can be used as an alternative fuel in electricity production. Other steel by-products can also be reused in the production of concrete, fertilizer, plastic, and paint.

Table 1 - Effects of constructing structures on the environment (Council, 2015)

Environmental Impact	Intrinsic Energy	Contribution to climate change	Air toxicity index	Water toxicity index	Resources used (weight)	Waste products
Metal structure	53%	23%	74%	247%	14%	-21%
Concrete structure	120%	50%	115%	114%	93%	37%

Secondly, steel frame structures help the constructors avoid the concrete dry periods and adhesion of the concrete minimizes the risk that occurs during construction management. Site preparation stages are simplified, which means finishing is complete in a short time which also saving labor and resources. According to Table 2, short construction time and minimizing the number of labor could save 20% to 50% cost.

Table 2 - Comparison of steel construction and reinforced concrete structures (NUCE, 2000)

	Reinforced concrete structure	Pre-engineered steel structure	Comparison of steel structure and reinforced concrete
Size	Suitable for house span 5-8m	Even suitable for large spans of 20-30m	Save 20-50% of costs for large-scale projects
Structure fabrication	Fabrication at the site, going through many stages and takes time	All components are pre-engineered in the factory, quality is controlled, high precision, automation, optimized	Reduce more than 90% of fabrication time on site.
Construction progress	1 House 100m2 x 3 floors with average progress of 6 months	1 House 100m2 x 3 floors with average 3 months construction progress	Construction progress is only equal to 50% of reinforced concrete houses.

Thirdly, besides the steel structure, the cover panels are specially crafted for use in sound insulation, heat insulation, and fire protection. The essence of sound is that sound waves travel through space, and are especially easy through solid walls. However, the DALICS method's assembly panels aim to create sound gaps, preventing sound from spreading between separate spaces. This noise reduction effect, called "Dense-Empty-Dense", is made up of the "dense" part of each panel (thin, only a few centimeters thick) and the "empty" part in the center containing air (the larger this void, the higher the sound insulation) or fiber (glass or basalt) (Dubosc and Huy, 2014). Partitions, façades, and floors play an essential role in combating the spread of a fire, and pre-engineered drywall material. Pre-engineered plaster walls were

derived from the materials to build military camps during World War II and were realized as a kind of thin wall that has fire-resistance: At high temperatures, the water in the wall crystallizes with the plaster and creates an effective protective barrier (Fig 2). Besides, dry floors (Fig 3) are made by the mechanical assembly of industrialized materials. It consists of a metal tray that rests on the beams and which alone performs the load-bearing function. Spans can go from 2 to 6m. It contains plasterboard 13mm panel, screwed 12mm panel, asymmetric beam, glass veil, 200mm high steel tray, hanger, false ceiling frame, insulating, and plasterboards of 13 or 15mm.

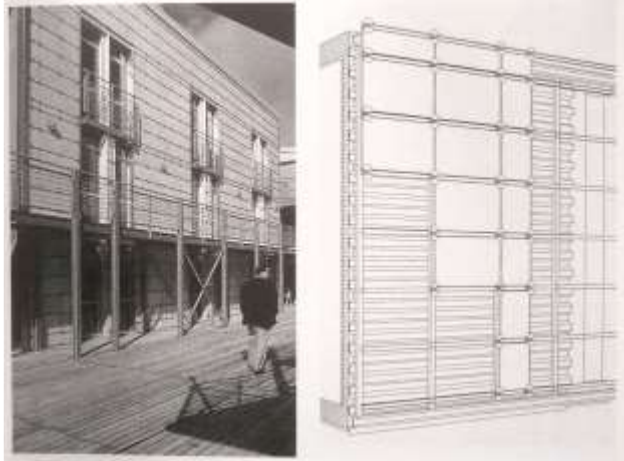


Fig. 2 - Drywall insulation – fireproof (Source: Eric Dubosc)



Fig. 3 - Sandwich floor (Source: Eric Dubosc)

Fourthly, steel buildings have the highest flexibility to design the architectural form: easy scaling, adding, and connecting to the old system flexibly, instead of having to change the new column grid system. There is no need to demolish the structure of the old system to be extended (since it is necessary if there is a reinforced concrete frame house). This allows architectural designers to have more options with a variety type of architectural shapes. It also greatly affects the organization of cubic spaces: not coarse, not confined, and monotonous.

1.2 Background of Building Industry in Vietnam

In the early 20th century, construction technology using assembled steel structure frames has been brought to Viet Nam by French colonial. At that moment, the Eiffel Tower has been completed for more than 30 years, the French construction industry thrives with steel structures, and with the advantages of compact transportation, easy construction, they have been selected as the material of French buildings in Vietnam with the aim showing the strong power of the French colonial government in the colonial land. The most famous work completed in Vietnam in the first decade of the 20th century is the Hanoi Opera House, whose structure is built entirely of steel and covered with bricks. As one of the biggest scale buildings at that time, the Opera house was built in the capital to serve the needs of French music enjoyment. It was the most luxurious and righteous building at the time of its construction. All large floors, balconies, and staircases are made of steel beams with a combination of studs and shaped steel beams and rolled tiles to create a floor surface. There are a stage and an audience room of 24x24m inside which has a total of 598 seats (Phuong, 2018).

The method of building with assembled steel frames and brick walls was popular in public work constructing large-spans. The range of building types is large from luxury buildings to industrial factories, transportation infrastructures. There is the Long Bien bridge with entirely assembled steel, inheriting the technical advances of that period: the 1682m long bridge with 19 spans, 1 train lane, and two side aisles for cars. The bridge was built in just 4 years and 7 months compared with the expected construction period of 5 years and the construction cost does not exceed the approved budget (1944).

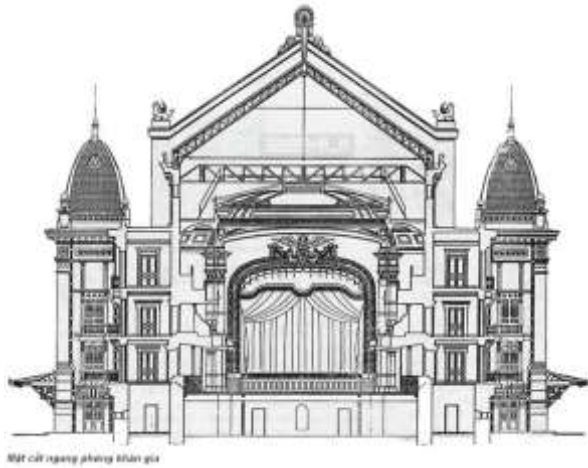


Fig. 4- Section of Hanoi Opera (Source: National Archives Center I)



Fig. 5 - Long Bien bridge in 1950 (Source: National Archives Center I)

The other significant steelworks at that time were the Gia Lam train factory, the Hai Duong winery, and the airport terminals in Gia Lam and Bach Mai. After peace was restored in the 1950s-60s, the North of Vietnam began to build a base for industrialization, included heavy and light industrial factories, they required a great number assembled frames. However, at that time, steel was a rare material because it had to be imported from socialist countries. Therefore, steel is only used for large factories with high columns and wide spans such as the Thai Nguyen Iron and Steel Complex. In other cases, only reinforced concrete is used. During the 1970s and 80s, the main construction work was to restore damaged structures and build new light industrial workshops. The new structure formation is a mixture of concrete columns and steel trusses. There is only one type of steel frame imported from the Czech, with a span of 12-15m, made of steel pipes, composite steel columns, and purlins by cold-rolled thin-wall components. The factors of comfortable transportation and fast completion time were a priority instead of saving materials.

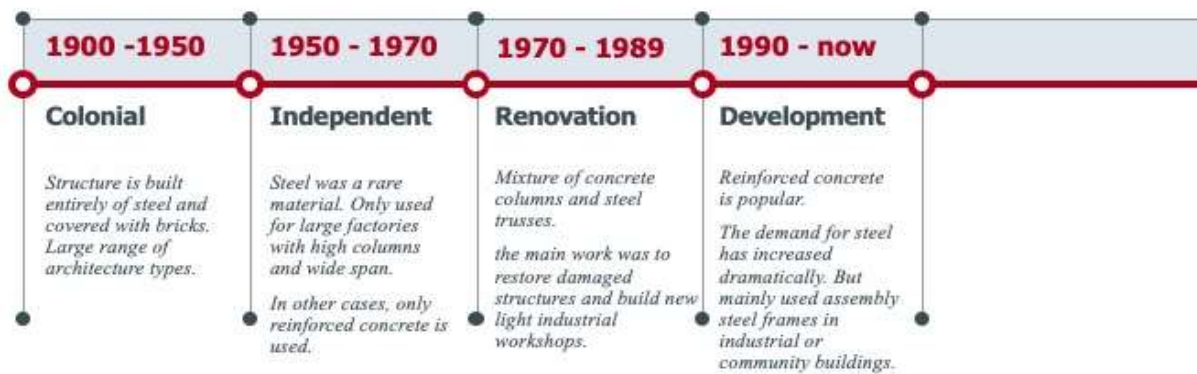


Fig. 6 - Timeline of Vietnam’s assembled steel development (Association, 2018)

And from the 1990s up to now, along with the rapid development of the economy and construction, the demand for steel has increased dramatically. Almost 100% of the factory is entirely made of steel. The heavy reinforced concrete roofs have been replaced with lightweight corrugated iron roofs placed on thin-wall purlins (Phuong, 2018).

Infiltrated into Vietnam from the early 20th century, but the Vietnamese mainly used assembly steel frames in industrial or community buildings, rarely in the residential or retail field. The finishing system was primarily plastered brick walls as locally produced material. The construction often had a raw format, focused on the production function, and less paid attention to aesthetics.

While steel is an expensive material, reinforced concrete appeared with available materials such as limestone, clay, sand, etc that can be easily found in domestic natural sources without high production techniques, small amounts of steel need to be used, so it became a suitable method and widely applied in various construction types from residential, retail buildings to public and commercial buildings. The widespread reinforced concrete lead to the diminishing role of the steel frame in the construction field.

According to the Ministry of Construction of Vietnam, like in many other countries, most buildings have used reinforced concrete as main building materials (Phong and Tri, 2020). After the war period, the reform policies launched in Vietnam in 1986 known as Doi Moi (translated literally as ‘Revolution’), which force the construction industry entered

a boom period when construction demand surged. Although approaching Vietnam later than steel, reinforced concrete was chosen because it can be constructed on a small scale and manually, suitable for economic-construction statement at that time. In another hand, cement production which is material to produced concrete also increased dramatically, data from the Ministry of Construction showed that in 2017, production was 78 million tons, as of December 2018 it was 83 million tons and in 2019 it was 90 million tons. The concrete composition consists of 12% cement, 80% sandstone aggregate, and 8% water (Minh, 2005). Thus, the volume of concrete produced corresponding to 90 million tons of cement (2019 data) needs 250 million tons of sand and stone and 60 million tons of water. This increases the pressure on natural resources when it is necessary to expand, increase exploitation of limestone, clay, stone, sand, etc and at the same time cause greenhouse gas emissions. The exploitation of natural materials actually has a great impact on the living environment and will lead to serious consequences if the exploitation is not done properly with the technical process. Recently, some embankments along the Red River (Hanoi) were eroded and the riverbed in some locations dropped 2-3m due to illegal sand mining. The river flows and threatens the safety of riverside villages, the number of people affected can reach many millions.

At the same time, in Vietnam's "Socio-Economic Development Strategy" to 2030, with a vision to 2050, the Government focuses on sustainable development orientation for all industries, including the construction industry. This requirement requires the construction industry to reform and develop other construction methods that can replace reinforced concrete and minimize the exploitation of natural materials. Specifically, the aim of the Strategy for the development of science and technology of the Construction industry to 2020, with a vision to 2030 is clear: develop and apply construction technologies for sustainable development and response to climate change (Construction, 2018). Therefore, although currently reinforced concrete construction systems occupy an important position in the construction industry. But in the near future, there will be many construction methods appearing and competing, in which assembled steel construction method with high precision and uniform quality elements are potential.

1.3 Current Status of Assembled Steel Frames and The DALICS Method in Vietnam Construction Industry

According to the Vietnam Construction Association, the Vietnam construction industry from 2017 to 2020 has many positive changes when construction activities increase about 9 - 9.2%. In addition, despite being in a recession due to the effects of the COVID-19 pandemic, in the first 6 months of 2020, industry and construction had good growth, nearly 3% compared to the same period in 2019 (Duong, 2020). As the need still increases, the real estate market is in strong momentum, the production has no signal to decrease steel production output in the following years.

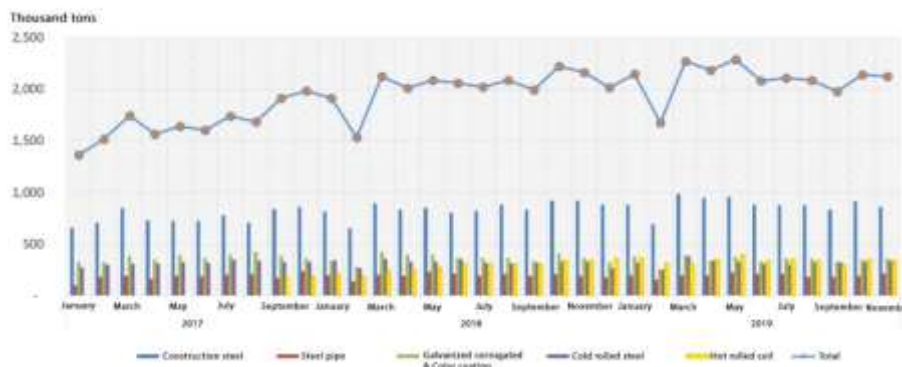


Fig 7 - Domestic finished steel production in 2017, 2018 and 2019 (Association, 2020)

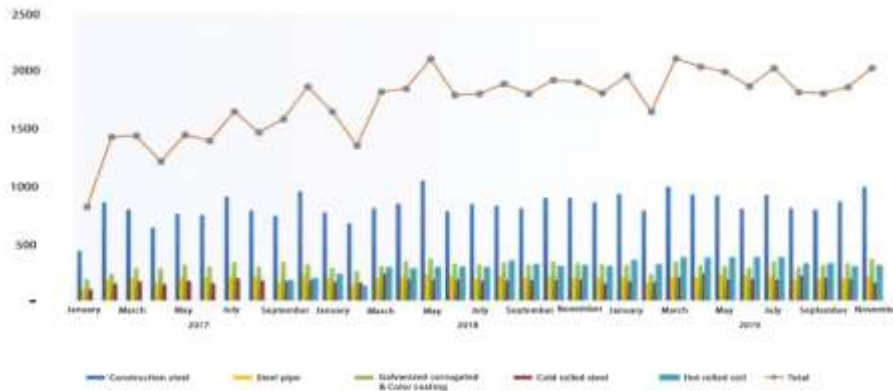


Fig. 8 - Finished steel sales in 2017, 2018 and 2019 (Association, 2020)

However, mainly domestically produced is round steel, cold-rolled steel, steel production materials for fabrication of assembled steel structures still have to mainly import: shaped steel (cast steel) and steel complex (components are welded with a combination of steel plates). An only a small number of factories have the ability to produce them because the production system of the domestic steel industry has not been completed, so they mostly supply steel for reinforced concrete, steel pipe, box steel, but some other products such as plates, sections, and weighted steel are still imported from abroad, the consequence that the price is higher than compared with the other types. In the past, the units often used large amounts of cast steel such as I, H, U, V pipes in industrial construction steel structures, nowadays, most developed countries apply technology and use more sheet steel. Steel structure details that are cut from steel plates, welded together are called assembled steel buildings with many advantages, especially saving up to 15-20% of used steel volume, shorten construction time. With their outstanding advantages, assembled steel is gradually being paid more attention and widely put into construction. Market demand has led to a significant increase in the number of assembled steel suppliers, according to a survey of Reed Tradex (Thai-land exhibition organizer company), high-quality pre-engineered steel companies in Southeast Asia, including BMB Steel (VN), Zamil (FDI), PEB (FDI), ATAD (VN), etc (Association, 2016).

According to the Vietnam Steel Association, the growth rate of the pre-engineered steel market in Vietnam is 15-17%/ year in the period 2016-2019. With the advantage of low maintenance costs and easy to expand in the future, now more than 70% of industrial factories in Vietnam using this product. In fact, besides low cost and convenience, assembled steel structures also create luxury for residential or office buildings which requires a high aesthetic level. Many buildings and offices are now using steel and glass frames as the optimal solution. That's why outside using assembled steel for factory buildings, assembled steel frames tend to apply in many types of structures with complex architectural designs such as public buildings (exhibition centers, airport terminals, etc) and residential housing field.

The DALICS is a new step in assembled steel architecture. While this construction is strongly produced, the cover panel also increasingly diverse in materials, styles, and designs such as large tempered glass panels, cementboard panels, gypsum boards, which is the premise for the development of the DALICS method in Vietnam. Thanks to features such as water-free constructing process, easy transport and assemble, and recyclable, the DALICS is used in many types of structures.

2. Research Method

2.1 Questionnaire Survey

Since there are no statistics on the number of assembled steel buildings built annually in Vietnam, the question is how to understand the situation, and predict the future orientation if only having the data of production and consumption. The authors come to a conclusion to consider seriously the stakeholders, who decide the number of building through their awareness of the market, the materials and technologies. So, we chose interviewing as a method to understand how people in the community affect the industry and also raise knowledge about how society awareness connect with industry development. In this research, the important questions that need to be answered as:

- Do the stakeholders aware of the advantages of the DALICS? (Yes/no question)
- Do the stakeholders interesting in the DALICS? (Yes/no question) and why?
- Do the stakeholder apply the DALICS in the building recently? (Yes/no question) and why?
- And will the stakeholder want to apply it within 3 years ahead? (Yes/no question) and why?

The question was sent to the interviewees through Google Forms, with the careful consideration of interviewee selection. Selected investors included 10 big corporations that owned real estate investment projects in many regions in Vietnam, which are large-scale and high-class and 90 small and moderate investors. The 10 big investor groups account for

approximately 50% of the national real estate market, a number of corporations developing in multiple fields, having a strong influence on the socio-economic life of Vietnamese people. They are:

- (1) Vingroup;
- (2) FLC Group;
- (3) VFI Group;
- (4) Capital Investment and Trading Joint Stock Company;
- (5) Hanoi Housing Development and Investment Corporation - Handico;
- (6) Dong Phat Investment Joint Stock Company;
- (7) Viglacera Infrastructure Development Investment Company;
- (8) Capitaland-Hoang Thanh Investment Company Limited;
- (9) Hoa Binh Auto Joint Venture Company Limited;
- (10) Hanoi Construction Joint Stock Company No.3.

About consultant survey options, including 25 big consultants and 75 small and moderate consultants. As the construction industry mainly using reinforced concrete methods, engineers and workers are also trained and practiced in a defined way for a long time, which is the general state of this community. For the users, the author has selected 187 people who are looking for housing to do the survey questionnaire. Most of them belong to the middle class (teachers, engineers, officers...), which is the major community in Vietnam society.

2.2 The Case Studies and Experiments

For public buildings, the DALICS applied soonest with the steel frame system covered by thin steel sheets, linked by screws. As technology developed, the frames and covers have been improved in quality and aesthetics also. The author himself has experience in designing and constructing this technology when becoming the winner in the design competition of Deo Ca Toll Station and Deo Ca Traffic Coordinator. Due to the specificity of the site located in the hilly and mountainous area, the assembly of lightweight structures makes the feasibility and safety high.

Deo Ca toll station:

- Time: 2017
- Location: Ca Pass, Phu Yen province, Vietnam
- Category: steel structure fabrication and erection
- Scale: 1 floor
- Total height: 21.45m
- Total length of the roof: 97.6m.



Fig. 9 - (a) Deo Ca toll station (Source: Author) (b) Deo Ca toll station (Source: Author)

Deo Ca traffic operator:

- Time: 2017
- Location: Ca Pass, Phu Yen province, Vietnam
- Category: steel structure fabrication and erection
- Scale: 4 floors
- Total height: 13 m



Fig. 10 - (a) Deo Ca traffic operator (Source: Author)

(b) Deo Ca traffic operator (Source: Author)

3. Result

3.1 Questionnaire Survey

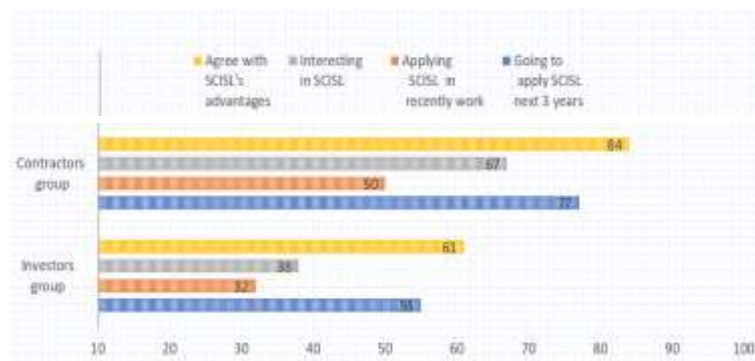


Fig. 11 - The chart to show the survey result of investors, contractors group's attitude to accept DALICS method (Source: Author)

According to the survey result, 38% of the investors interested in the DALICS method while 72% do not care much because they think that this technology cannot be applied in their work yet. 61% agree on the benefits of this construction technology included 32% they are applying the method in work, and 55% will accept to use this technology in the near future (next 3 years). This data shows the wary attitude about the reservations of new technology by large investment groups. The apparatus of these corporations are often large-scale, especially in architectural design and construction. They have specialized design, construction, and execution departments with well-trained staff. These are their advantages but also disadvantages when they want to train-form construction technology. Converting a system specializing in the construction of reinforced concrete to the DALICS specialization will cost a large amount of time and finance. About consultant interview, while reinforced concrete methods allow certain errors, the method of the DALICS construction with fewer error details. 84% of contractors believe this new construction method has benefited them, however only 67% interested in this method; 50% have applied this method in their work. And 77% confirmed will apply the DALICS in the next 3 years. Construction contractors are the people who know best about construction methods, so it can be seen that in the near future, the DALICS method will be trusted by contractors to perform more construction. For the users, the author has selected 187 people who are looking for housing to do the survey questionnaire. Only 36% of users agree with the advantages of the DALICS method since 46% interested in the DALICS. 75% do not want to live in a house made by the DALICS method (with steel) and 25% agree to choose a house like that if they find one.

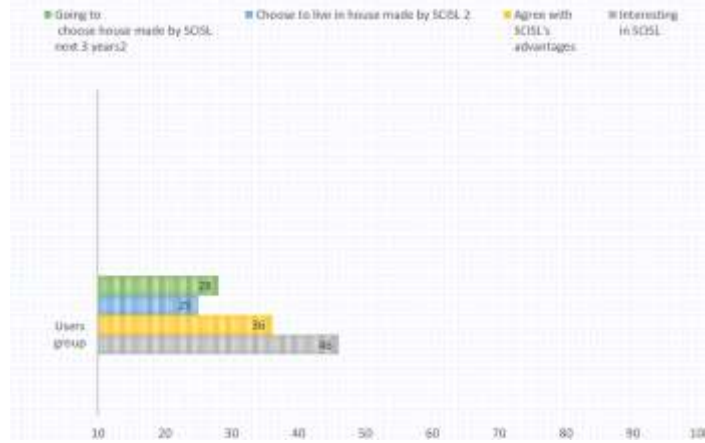


Fig. 12 - The user group's attitude to accept DALICS method (Source: Author)

Since the reinforced concrete construction method in Vietnam is popular, the people in the user group mostly do not pay attention to the DALICS method. However, in order to save living money, many users have tended to choose the DALICS method after hearing about its benefit.

3.2 The Case Studies and Experiments

As an infrastructural construction, the toll station is a large overpass project, thus maximizing the advantages of this method, the total construction investment cost is only 80% of the traditional method, not to mention the interest costs and the construction into operation 6 months earlier. The works are constructed synchronously outside the site for the foundation and produce the components at the same time in the factory, so the total construction time of both works only takes 3 months instead of 9 months according to the reinforced concrete method. Both buildings are designed with white painted assembled steel bars to reduce the heavy visual of the steel structure. The architectural form is lightweight and elegant thank to the flexibly organized structures which is easy to maintain and renovate, so far after 4 years of working, the project is still in a good statement.

According to the author's experiment, structures using steel structures can achieve slenderness without the limitations of reinforced concrete. To comparing, if a structure has the same cross-section, the steel structure can extend 1.4-1.5 times further than the reinforced concrete structure. The steel structure is light and flexible under seismic load and minimizes the effect of seismic on the structure. Architectural works using steel structures show off the structures as beauty, so with their accountability, when the work is overloaded or deformed, it will be easy to recognize for timely remediation. The wall which separated interior spaces is made of gypsum boards. Through the above practical works, the economic and technical benefits of the DALICS method are clearly presented. Using this method can save for the investors 30-40% of the construction cost, equivalent to many billion VND.

4. Analysis and Discussion: The Directions of the DALICS Method in Future of Vietnam Construction Industry

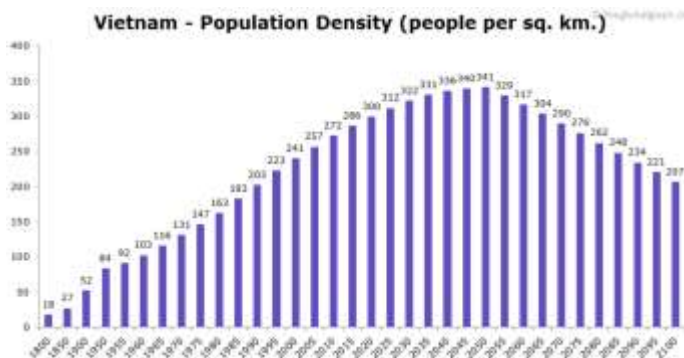


Fig. 13 - Vietnam population density prediction (Population, 2020)



Fig. 14 - Housing demand in Vietnam is huge (Journal, 2020)

According to Fig.13 and Fig.14, the Vietnam Population density prediction shows that Vietnam will require a huge amount of housing in the future, which pushes up the high growth rate of the construction industry. With the average population growth rate in both Hanoi and Ho Chi Minh City at about 2.2%, the demand for housing construction in these two cities is assessed to be extra-large (Association, 2016).

At the same time, the main directions of the Government on building materials development in the future also focus on smart building materials, assembled building materials, and energy-saving. The most outstanding is the national technical regulation on construction works using energy efficiency and reusing building materials (Construction, 2017). Therefore, steel structures along with their advantages have a great opportunity to expand and develop. As predicted by the Vietnam Construction Association, in the coming years, the steel structure will be used more and more widely in public and civil works.

However, about the DALICS method, it's a different story. For private and small scale buildings (houses, offices, retail buildings, restaurants, etc), these type of projects 10 years ago have been constructed with reinforced concrete as the only choice. Recently, the assembled steel frame started to be used more by the clients and consultants in this segment. Assembled steel frame houses become popular as they are applied in almost every type of buildings, such as residential housing, offices, restaurants, retails, etc. For example, this is a 5-story office building (400m²) that was implemented in 2015 by VS Steel Steel Structure Company. Structures included assembled steel frame, concrete deck floor panels, covered by glass and brick walls.



Fig. 15 - (a) During constructing (Company, 2019)

Fig. 16 - (b) After completion (Company, 2019)



Fig. 17 - Prefab house for workers (company, 2015)

The process of foundation construction and steel structure production at the factory took place in parallel for 15 days. After pouring the foundation concrete, pre-engineered steel structures are transported to the erection. The construction time of the steel frame on site is 7 days and then install the deck floors. The total construction time of the rough part including foundation works for 5 floors only takes 29 days. It is easy to see that during the construction process, the steel structure system saves the owner time, labor, and money, even if it is only assembled steel structure, not the DALICS method.

Similarly, in the other sectors such as housing, restaurant, retails, etc, steel structures are also widely used. Most of these works are covered with glass or bricks with an average investment level or upper. Plaster walls are used for sound and heat insulation purposes but for interiors. The DALICS method has also recently made its way into the field, one has become quite popular as low-cost assembled accommodation for low-income people, such as workers and employees. As the Vietnam industry developed rapidly, the number of workers need a large number of houses which confused the government. This type of house is favored by investors due to its low investment cost, fast construction, and easy dismantling (Office, 2020). Along with it, the house has a low lifespan, low wall durability, difficult to withstand natural impacts, and the aesthetic value is lower than that of steel structures types surrounded by bricks or glasses. However, it solves the urgent housing need for low-income people and enables them to stabilize their lives at a moderate cost.

Since the reinforced concrete construction method in Vietnam is popular, the people in the user group mostly do not pay attention to the DALICS method. However, in order to save living money, many users have tended to choose the DALICS method after understanding its benefit. The image of panels to cover the house with cheap prices is making this method associated with a low-market segment in the civil sector. The form and design still have many limitations, have not yet attracted people in the medium and higher segment, although of good quality.



Fig. 18 - Model of house made by the DALICS method (Forum, 2020)

This shows that, in order to guide the DALICS method to approach the civil engineering field, it is necessary to promote aesthetics. For example, in Thailand and the Philippines, which are Vietnam neighborhoods, civil works for assembling are popular with beautiful and sturdy shapes, the majority in society are willing to pay to own such houses. For the public sector, the DALICS method is dominating with a long span, large volume assemblies reduce the cost for the investor while still retaining the unique, aesthetics as well as durability in use of the project. This is an outstanding and competitive advantage, helping the DALICS to develop in the future.

5. Conclusion

With the advantages that structural steel can bring to the construction industry (not reinforced concrete or any other method), this method has great potential for development in the construction industry in Vietnam, where reinforced concrete is leading. The market is open thanks to the DALICS benefits, however, in the recent future, to be widely used, the DALICS have to improve more to come closer to Vietnamese living. Vietnam will have a total new house generation which represent for new technologies and awareness, which could support the people to get their own home with suitable price.

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