Enablers and barriers of seismic-resistant technologies adoption in the construction industry: A case study

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Abstract

Earthquakes have hit New Zealand in quick succession with no respite expected in their frequency in the future. The latest earthquakes have had a severe impact on the economy of the country. Therefore, several new methods and technologies are proposed to the construction industry that aims at reducing the side effects of damages, including seismic-resistant technologies. However, the low level of trust towards the performance of these new technologies poses the main challenge that could also affect the adoption process to them [1]. The literature review associates the level of trust to 36 factors [2]. A survey of the New Zealand construction industry identified 17 of them as significant influencers. This paper provides further details on the role that these 17 factors play as enablers or barriers in the adoption process to seismic-resistant technologies. The data collection stage involved an online survey from a random population of the construction industry, including clients, contractors, and consultants. Four seismic resistant technologies, Resilient Slip Friction Joint (RSFJ) [3], Pres-Lam [4], Lead Extrusion Damper (LED) [5] and the Sliding Hinge Joint [6] were considered as the case studies. From the 215 who were invited, a total of 90 responses were received. The study excluded 15 incomplete responses. Discussion is provided on the reasons for which the factors are tied to an enabler or a barrier role. The results enhance the understanding of perception and judgment process by the construction practitioners in their technology adoption decision.

Keywords: New technologies, trust, uptake, barrier, the enabler.

1. Introduction

New Zealand has been affected by significant earthquakes over the years similar to any other seismic prone country. Despite all the improvements introduced by developing the codes and standards since 1932, the country still suffers substantial losses after each earthquake. As a consequence of a large number of earthquakes which happened before in the country, the economy of the country has been distracted. Several solutions have been considered for addressing this issue, such as introducing new seismic technologies. For protecting buildings and savings lives in severe earthquakes, structural engineers design building with more expected behavior by using these seismic-resistant technologies. The adoption process to these newly introduced technologies is very slow and turn to an important challenge for the construction industry [1]. A comprehensive literature review has been conducted to identify the factors which could influence the adoption process to new technologies. 36 factors have been identified based on the literature. A questionnaire survey was conducted among the construction field experts to refine the list of the factors to the most significant ones. As a result, 17 factors were detected that are presented in table (1).

Table (1). The most significant factors influence the adoption of new technologies

Factor	Significance level
The cost of post-earthquake maintenance	1
Ownership of the project	2
Lack of experience with the technology	3
Preference of the designers	3
The market price of the technology	3
The level of customization provided by the technology	3
The designers' expertise in using the technology	4
The local supply of the technology	4
Availability of trained workforce at the construction site	4
Availability of construction material	5
Size of project	5
Type of project	5
Procurement system: Local representative	5
Availability of trained workforce at the construction site	5
The complexity of the design and construction method	6
Access to advanced equipment in the construction phase	6
Preference of project owners	7

The role that these factors played as an enabler or barrier in the adoption process of the New Zealand construction industry is discussed in this paper. As mentioned, the following four different seismic-resistant technologies have been considered as case studies considering the fact that of these technologies have recently been introduced and implemented to New Zealand construction industry and the industry adaption to these technologies was slow:

1. Resilient Slip Friction Joint (RSFJ): is a newly introduced seismic resistant technology which dissipates earthquake energy, restores the structure after each seismic event, has no need for sacrificial components and no post-event maintenance required [3].
2. Pres-lam: is a mass timber construction method that employs high strength unbounded post-tensioned elements (such as steel cables or rods) to connect timber beams to columns, or columns to walls and eventually foundations. the pre-tensioned elements clamp the members and keep the integrity of the building. The result is a more compact and even stronger timber building [4].
3. Lead Extrusion Damper: is another type of damper which utilizes the hysteretic energy dissipation properties of metals [5], and
4. Sliding Hinge Joint (SHJ): is a low damage alternative to the traditional beam-column welded connections of the seismic Moment Resisting Steel Frames (MRSFs) [6].

“Enabler can be defined as equipment and/or methodology that, alone or in combination with related technologies, provides a way to generate giant leaps in performance and capabilities of the user’’ [7]. The industry adoption process to new technologies will be accelerated by finding enablers factor and reinforce them [7].

“Barriers to Adoption are all the things that prevent using a new product. They may range from inconveniences, the need to buy ancillary products, the difficulty getting it to work or the learning curve’’ [8]. By finding barriers for industry adoption to new technologies and try to fix or improve them, the speed of the adoption process will increase.

2. Research design

The industry adoption to new technologies has been slow in New Zealand construction field [9]. To address this issue, firstly, a literature review has been conducted to explore the factors that facilitate technology adoption from closed researches. Secondly, a survey was designed to seek the most significant factors that cause industry adoption for the New Zealand construction industry. At this stage, another survey has been designed to find the roles these factors played as enabler or barriers.

2.1 Survey design

A questionnaire survey was designed by Survey Monkey and a web link generated. The weblink has been electronically distributed to 215 respondents. At the first part of the survey, four different seismic-resistant technologies were explained in detail, and in the second part, the respondents were asked to rank the factors as enablers or barriers.

2.2 Data collection and analysis

As mentioned before, a survey was designed and released to the construction industry experts in New Zealand. The experts were comprised of (but not limited to) general contractors, consultants, clients, project managers, mediators and arbitrators. Their years of experience were considered more than 5 years, and they should have experience in working with new technologies. A total of 215 experts were invited, 90 responses were received. Among which 15 responses were disregarded because of non-completion. Random sampling was used in the process. The collected data were analyzed by using the binomial test. We expected the factors to have an equal chance for being enabler or barrier, so the test proportion was set to 50%. A sample model of the result is shown in Table (2). The result of the binomial test showed no significant difference given the fact that there was general agreement about which one is enabler or barrier.

Table (2). Binomial Test

		Category	N	Observed Prop.	Test Prop.	Exact Sig. (2-tailed)
Governmental project	Group 1	Enabler	68	.91	.50	.000
	Group 2	Barrier	7	.09		
	Total		75	1.00		

3. Discussions

Adoption to technology is a key subject in the construction industry. It is no secret that technology is constantly evolving and rapidly changing the landscape of the construction industry. This ranges from increasing the efficiency of day-to-day operations to manufacturing new and advanced high-tech products. Typically, it is the companies that can adapt and embrace technological change that ultimately survive the competitive business climate [10]. Based on the conducted survey, the enablers and barriers are showed in Table (3). The following sections discuss the reasons for being chosen as an enabler or barrier for these factors and how to reinforce enablers or fix the barriers.

Table (3). List of enablers and barriers

Enablers	Barriers
Using advanced equipment in the method of construction	The client resistance to change
Ownership of the project	Complicated design and construction
Type of construction projects: Commercial and industrial	Origin of the component
Ability to customize products	Cost of the new technology
A local supplied technology	Lack of time to complete a project
Trained personnel	
Structural engineer's recommendation	
Post-earthquake maintenance cost	
Experience with the new technology	
Availability of labour and construction material	
The scale of the project	
The expertise of consultants in using new technology	
Strict quality control and certificate of performance	

4. Enablers of technology adoption

The 13 following factors were identified as enablers in the survey, the reasons and how to reinforce these factors for technology adoption in future is discussed here.

4.1 Using advanced equipment in the method of construction

Grange and Buys [11] identified that the technology adoption will increase by the scientific changes offered by the newly introduced technologies and products, cause these scientific changes to make them simpler to work with and more uncomplicated to implement. In our case studies using more advanced equipment in the method of construction has identified as one of the most important factors which cause easy and fast adoption to these new technologies [12]. Construction methods refer to the procedures and techniques that are used during the building process [13]. For example, one of the case studies (RSFJ) can be installed in a building through an easy process given it is a pre-fabricated product, which increases the acceptance of this technology among the construction industry users [3]. In such cases, introducing the pre-fabricated types of construction products will enhance the adoption level [14]. These types of new technologies and new products will be more accessible by a wide range of users and a wide range of constructions, and it will result in more implementation flexibility in these type of products [14]. Another way is in the prospect of mechanization and instructed automation in new markets to solve the issue of construction works which up until now have been limited to manual procedures [15]. It is believed that the pace of work can be increased while reducing the required man-hours [15].

4.2 Ownership of the project: governmental projects

If a product or a technology addresses the specific needs of the market or customer, the chance of being accepted will notably increase in the market compared to its competitors. De la Tour recognized the market factor as one of the most important enablers in technology transfer [16]. Market factor refers to any external agent that affects the demand for or the price of a good or service [15]. Using a new method or an innovative technology sometimes may secure business in the market [11].

To speed up technology adoption, if there are some regulations and standards for buildings set by the government, a more suitable platform may be provided. For instance, for the governmental project, designers will be encouraged to use newly introduced seismic resistant technology to provide life safety in addition to reducing the post-earthquake repair cost [17]. As a result, seismic-resistant technologies can play a significant role in keeping these types of buildings functional during and after earthquakes. Respondents chose this factor as an enabler.

4.3 Type of construction projects: Commercial and industrial

Based on the study provided, the commercial and industrial types of projects are enablers to adapt to new technologies. Firstly, life safety is a priority in both of them, which some of the seismic-resistant technologies can guarantee this achievement. Secondly, by using these technologies in a commercial building, the post-disaster financial loss will significantly decrease, which is quite important for business owners [18]. After disasters such as earthquakes, industrial building such as power providers or water providers should remain functional and continue providing basic needs for the community [18]. This may be possible by using some of the newly introduced technologies.

4.4 Ability to customize products

“Customization” refers to a company's ability to efficiently “mass” produce products that meet individual consumer desires and needs. A common way to carry out “mass customization” is to offer a basic package for a product and then offer customers a range of features they can add or subtract. “Customization” carries the “benefits” of high product sales associated with “mass” production, and by offering a foundation product and giving customers a range of models or the option to add features of their choice, increases customer satisfaction and gives a business increased sales [19].
Technological abilities of suppliers’ have been identified as an important enabler of Technology Transfer (TT) [20]. Technological abilities to deliver good and technically sound output should include the main characteristics of the organization who take the honours of developing new technology or new product. For example, if a company does not have enough resources, it may not be able to deliver quality products [11]. As a result, a strong provider company with good quality of resources can produce customized products. When a product can be customized based on customer needs, it means that it can be produced in any size and it can be used in any part of the construction [19]. This ability makes this product quite strong in the market compared to other technologies [19]. Most of the time, new technologies and products can be customized based on customer needs. When a product can be manufactured based on the soil requirements or the location of the building, the adoption process to this technology will rise sharply [19]. In the future, designing new technologies with the advantage of flexibility in production and implementation may cause better and faster adoption process.

4.5 A local supplied technology

A new technology or a new product which is produced in a country should be compatible with local society [11]. There is a direct connection between success or failure of a product in making its way to the local market with the local suitability of the technology [11]. Generally, technologies that are produced locally have the advantage of minimum transportation cost. It facilitates a shorter lead time that enhances the adoption process [21]. One of our case studies (RSFJ), is a made-in-New Zealand technology that is compatible with the requirement of the local industry. It also benefits from supplying local representatives that makes support easily available. It ensures the availability of the responsible person if there is a query or a special request (e.g. maintenance and support). As mentioned before, in future, using localized products may minimize the transportation cost in buildings, and they can be delivered to the projects in minimum time. So, time and cost will be minimized. Also, certifying technologies which have been developed and fabricated locally is much easier, because they can be tested in the laboratories. To conclude, using localized technologies has the advantages of availability and minimum transportation cost, which speeds up in the process of adoption.

4.6 Trained personnel

For developing a new product or a new technology, we may need trained expertise personnel to more secure transfer of technology[11]. Jobholders themselves have internalized this insight: A 2016 Pew Research Center survey, "The State of American Jobs," found that 87% of workers believe it will be essential for them to get training and develop new job skills throughout their work life to keep up with changes in the workplace [22]. Providers of technology are the best references to hold workshops and seminars as an efficient solution to get the engineers familiar with the technology[22]. Presenting case studies of the real-life projects that have adopted the new technology could also be effective, and also knowledge of personnel in receiver organisation has been recognized as a vital factor in technology transfer process [23].

4.7 Structural engineer's recommendation

End users are the main testers of the new methods, or new technologies and their feedback may result in faster acceptance of the technology [24]. Also, customers are motivated to pay higher prices to new technologies for higher quality or easier installation [25]. For our case studies, structural engineers have been considered as the end-users who have the main responsibility for deciding about using these products in the projects [24]. Given the importance of the role of the structural engineers in the design process of the structures, they are the key characters deciding about adapting a specific structural solution or a new structural technology [26]. Therefore, it is imperative for them to be technically satisfied with the technology and be convinced about the cost of the technology compared to the overall value of the building [26]. Overall, when structural engineers (as the gatekeepers who should decide about using the new technologies) are technically happy about the advantages satisfied with the cost, then they play the enabler role in the adoption process of new technologies. To achieve this goal, holding technical presentations for structural engineers by suppliers of the new technology about the technical advantages of new technology, how to design, model and implement new technology in new projects or upgrade projects would be very effective approach [27]

4.8 Post-earthquake maintenance cost

The 2010–2011 Canterbury earthquake, which involved widespread damage near the Christchurch Central Business District, left this community with more than $NZD 40 billion in losses (*20 % GDP), demolition of approximately 60 % of multi-storey concrete buildings (three storeys and up), and closure of the core business district for over two years [28]. In the Christchurch earthquake event, there were some cases that the cost of replacing the building was less than the cost of repairing, where the insurer considered the replacement of the building [28].

Appropriability approach follows the belief that 'good technologies sell themselves'. Some of the newly introduced seismic-resistant technologies may cause post-earthquake maintenance cost decreases because the system is damage avoidance. This maintenance-free characteristic can also be interpreted as insignificant repair costs after the earthquake. Having this factor ranked as the most important determinant indicates the significance of individual experience in building trust when adopting new technology. Liability is considered for a technology when it will experiment completely, and as a result, it will represent less uncertainly to the customer so it can be accepted easier [29]. Given these types of new seismic-resistant technologies can be damage-free and some capable of restoring the building to its original position, they could have a significant impact on minimizing the costs associated with damage recovery as well as the business interruption after severe earthquakes. The main issue is that clients do not consider maintenance cost in their initial cost estimation of the project [30]. As a result, they may find the price of the new technology relatively higher compared to more conventional technologies. However, as mentioned, by using seismic-resistant technologies with the advantages of self-centring and energy damping in construction projects, the post-earthquake maintenance cost will be decreased. These reasons together made the respondents to choose this factor as the enabler for technology adoption from construction industry people point of view.

4.9 Experience with the new technology

The adoption process for new technologies is extremely slow [31]. The speed of transferring the experience of using new technologies will be decreased because of poor communications inside and outside of the companies [11]. The high level of internal communication will result in better technology adoption to new technologies and getting familiar with their new advances which they will bring in [11]. Holding high-tech workshops and preparing installation guides for the parties involved will promote the knowledge about the installation requirements [27]. Presenting case studies of the real-life projects that have adopted the new technology could also be effective [27]. Contractors with higher experience in working with new equipment will have a higher trust in the new technologies and will adapt easier and faster to the new technology [27].

4.10 Availability of labour and construction material

In large projects, the availability of labour and construction material may cause difficulty in technology adoption [32]. Lack of skilled labours who had experience in the installation of new technology or using new method may lead to high hurdle in technology adoption [32]. Furthermore, as it was discussed previously, the use of materials which are locally available could significantly increase the likelihood of its adoption [32].

With the availability of labour and construction material, the speed of the constructing will sharply increase [33]. The process of installation for most of the newly introduced technologies is easy, so for the installation, highly experienced labours are not necessarily required. Production of new technology by using the type of manufacturing material which is locally available will be fast compared to the technologies which the material is not locally available and should be imported.

To achieve this target, firstly governments should encourage manufacturers of the new technologies to produce their technologies by using local material which is easily available, and they can cover part of the cost of the production to reduce the cost of production for the provider. Secondly, technology providers can arrange for installation guides for labours at the beginning of a new project to speed up the construction process.

4.11 The scale of the project

Large in scale projects usually have a higher importance level, so their earthquake performance is considered as an important factor by the decision-makers [34]. Good examples are schools, universities, hospitals, airports, etc. Also, for many large projects, the developer/owner's intention is not just selling the building to the customers but the service the building provides is important [34].

In large scale projects, the cost of new technology compared to the overall cost of the project turns to be ignorable (compared to smaller projects with fewer importance levels). In recent years, it was shown that newly introduced technologies, especially seismic-resistant technologies, can provide high-quality buildings by using them in structuring part. Also, as mentioned, usually the financial resources of the high importance large projects are less restricted and spending on high-quality earthquake-resistant technologies is more likely to be supported by the decision-makers [34].

4.12 The expertise of consultants in using new technology

When construction industry experts such as consultants get familiar with the advantages of new technologies, the adoption process will speed up [35]. To help the consultants with this, holding workshops and seminars, or presenting case studies of the real-life projects that the new technologies are adapted could be effective. Having more knowledge about new seismic-resistant technologies will encourage decision-makers to use them in their projects and facilitates the process of adoption [27].

4.13 Strict quality control and certificate of performance

An important advantage derived by a strict quality control is the satisfaction of consumers [36]. Consumers are benefited as they receive better service and better quality products on account of quality control [36]. It gives them satisfaction [36]. By producing better quality products and satisfying customer's needs, quality control raises the goodwill of the concern in the minds of people [36]. Based on the survey results, if this factor is considered for new technology or new product adoption, it will serve as an enabler. A certified product may display the trademark indicating that the product has undergone rigorous evaluation and testing to verify its performance to the specifications. Product certification, by definition, denotes the process through which a product is subjected to confirm that it has passed quality and performance tests. Product certification assures that the product is suited for distribution and public consumption. For most of the provided case studies, each device can be tested individually, and a certificate from the supplier is issued with the test result (possibly with a serial number of the device confirming its performance). New technologies or new products which had strict quality control in lab and certificate of performance will get adapted by customers faster and easier.

5. Barriers of technology adoption

Based on the survey, the five following factors were identified as barriers in which the reasons and solutions are discussed here.

5.1 The client resistance to change

Resistance to change is an important issue originating from the inside of the company rather than from the outside, and sometimes this reluctant to change may result in 'end of the organization' [11]. Therefore, the decision-makers of the companies should persuade to use new technologies for having more successful businesses [37]. In our case study, despite the higher initial cost, the new technologies could significantly reduce the post-event repair and maintenance costs, which gives the adopters more advantages compared to the conventional seismic solutions [3]. As a result, if the clients become more familiar with the advantages of these new technologies, they will be more likely to be convinced to adopt the new technologies and the observed resistance to change may reduce.

The other issue is that even though the designers may be happy with the technology and its advantages, but the contractors hesitated to use new tech only because of the potential risk related to timing. In other words, the contractor is a concern if they use the new technology, they may not be able to deliver the project on time. To resolve this issue, providers of the technology must make their technologies compatible with the current installation and implementation procedures. This means that no special installation procedure should be required for new technologies or if there is, there should be clear implementation guidelines in place for contractors, so the contractors will encourage to use new technologies in their projects and in the other words, they can accept the changes.

5.2 Complicated design and construction

Complexity may be an integral part of using new technologies in designing constructions [29]. Using new methods may need more complicated and updated designs. To compensate for this issue, a "design ready" pack of new technologies and new products can help the designers in the process [38]. Most of the times, the advantages of the new technologies are well recognized by the designers if the design process is not way too complicated.

5.3 Origin of the component

Country of origin is the country of manufacturing, production, or growth where an article or product comes from [39]. There are differing rules of origin under various national laws and international treaties, which may result in different quality in products. In the past few decades, China has grown to become a major economic power. The main reason to consider manufacturing in China is almost always the lower manufacturing cost, especially for mass-market products [39]. However, this factor has been chosen as a barrier to the adoption process because of many reasons. Firstly, customers are almost always willing to pay less for something even if it's manufactured in China. Secondly, China gets quite a bad rap for poor quality in manufacturing. Thirdly, shipping cost can be a real pain. When a product shipped from China, it should be packed up and put in cargo ships. Sometimes the vessel may sail around the globe, which leads to the high shipping cost and lead time. By performing strict quality control for each product or each technology by, customers may be encouraged to adapt to new technology and also as mentioned, providing a certificate of performance for each device can be very helpful to compensate for the lack of trust in made in China products.

5.4 Cost of the new technology

In some cases, the cost of new technology is higher compared to old ones, which can harm the adoption process. More scientific (and sometimes high-tech) alterations are included in the new technologies which result in higher cost and as a result, decision-makers prefer to use conventional technologies in their projects [40].
To tackle this issue, firstly, the overall lifecycle cost of the new technology should be presented to the decision-makers, which may result in more attraction in the decision-makers. Secondly, if the customers are convinced to bring in the post-earthquake maintenance cost into the account, the higher cost of the new technologies is more likely to be acceptable for them. Another solution is that the governments can cover some part of the cost of the new technologies or new products to better motivates the adopters [40].

5.5 Lack of time to complete a project

Getting familiar with new technologies needs time, which some project managers may see this as an issue. However, they should be convinced of the advantages that a new technology or new method can bring into the project compared to the conventional methods, specifically in technology transfer projects implementation [11]. Using advanced technologies and products in projects is more complicated and needs more time compared to conventional methods. One important reason can be a hard process of installation. Most of the times, construction projects are behind schedule and had the issue of lacking time [41].

6. Conclusions

There are several enablers and barriers to adapt to new technologies in construction. This study was undertaken to find the enablers and barriers for technology adoption in the construction industry field. A questionnaire survey was conducted by using the most important factors which cause adoption to new seismic-resistant technologies and was released between construction industry experts. In this research, we used the binomial test for analyzing the data. The results demonstrated that among the considered factors, 13 of them can play the role of enablers in the technology adoption process, such as using advanced equipment in the method of construction, post-earthquake maintenance cost, ownership of the project, ability to the customized product, a local supplied technology, trained personnel, structural engineer's recommendation, commercial and industrial types of projects, post-earthquake maintenance cost, experience with the new technology, availability of labour and construction material, the expertise of consultants in using new technology, strict quality control and certificate of performance. Also, five of them were identified as barriers, such as lack of time to complete a project, cost of new technology, the origin of the component, complicated design and construction and the client resistance to change. The reasons for each factor are discussed and potential solutions are provided.

Findings of this research will help technology developers to speed up the adaption process to new technologies by supporting enablers factors and improving barriers factors.

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