Article

Construction Technology Adoption Cube: An Investigation on Process, Factors, Barriers, Drivers, and Decision Makers using NVivo and AHP Analysis

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Abstract: Due to the complexity, high-risk, and conservative character of construction companies, advanced digital technologies do not become widely adopted in the short term, while vendors make determined efforts to overcome this and disseminate their technologies. This paper presents the methods of an investigation addressing the extremely complex issues related to the current practices of digital technology adoption in construction. It discusses how construction companies follow a specific logical process linked to need, project objectives, characteristics of the adopting organization, and the characteristics of the new technology to be adopted. The study aims to demonstrate a novel method of data collection and analysis including data and methodological triangulation techniques including the use of NVivo and AHP to explore how companies make the decision to uptake a new technology (e.g. advanced crane, tunnel boring machine or drones) by focusing on customer and vendor activities, their interactions, contributing factors, and people involved in the process. The major original contribution of this paper is to develop an innovative methodological Cube for investigating the Construction Technology Adoption Process (CTAP) covering technology adoption, acceptance, diffusion and implementation concepts. CTAP is a framework that delineates the phases of the process that customer organizations use when deciding to adopt a new digital technology and the parallel vendor activities. The significance of these contributions is that they enable vendors to understand how to match their strategies with customer expectations in each phase of the CTAP. It also provides a benchmark for new construction companies to use the current best practice of decision making. Future research is warranted to more clearly delineate any differences with developing nations or related industries such as mining and property management.

Keywords: construction technology adoption process; construction; mining; digital technology; diffusion; implementation; mix methods; grounded theory; thematic analysis; data and methodological triangulation techniques; AHP; NVivo

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1. Introduction

Innovation plays an important role in maintaining competitive advantage for firms and meeting the evolving demands of industry [1-3]. In construction considerable research indicates that new technologies have a large beneficial effect on overall performance, productivity, safety and efficiency [4-10]. For example, adding vibration to the rolling action of compactors exhibited a 260% increase in productivity during the mid-1980s when this technology was introduced by Caterpillar [11]. This leads to a growing focus on introducing new technologies [4, 12-15] to the construction industry by various firms in order to benefit from such advantages [16, 17]. According to Goodrum et al. [18], awareness of a particular technology does not ensure its adoption, and a "*series of interrelated events*" is required for the success of its implementation. Therefore, it is desirable to expedite the technology diffusion rate, and so technology vendors and suppliers try to facilitate the technology adoption process with supportive activities [19]. However, knowing which activities are truly supportive requires a deep understanding of the process undertaken by construction companies in deciding to use the technologies.

The size of the global construction technology market is estimated to reach US$145 billion in 2015 [20]. The report also shows that the top five largest manufacturers sold construction technology to the value of US$72 billion in 2013 [21]. The continuous increase in the number and value of new construction technologies at an ever-increasing speed, coupled with accelerating technological advancement of their functions produced a growing appetite for facilitating the technology uptake process by customers. Understanding this process is also important because the construction market is frequently subject to booms and collapses. For example, between 2012 and 2013, US construction machinery suffered a considerable decline of 21 percent in exporting construction technology from US$13.7 billion to US$10.8 billion [22]. These fluctuations have a huge impact on equipment and tool manufacturers, particularly recently established vendors. Thus, there is an urgent need to understand the process of technology adoption from two perspectives: a) customers – who make the adoption decision and seem to be under a "*bombardment of technological products*" [2], and b) vendors – who use different strategies to encourage the adoption of their technologies.

Since technology has the potential to enhance competency, it is recognized to be an important business strategy [23-25]. In addition, many governments encourage organizations to implement new technologies [26-29]. The ability to know how, why and where construction companies adopt new technologies is also critical, because it gives the ability to expedite the rate of technology diffusion by facilitating its adoption. According to Arts, Frambach [30], understanding this process is a critical insight for managers involved in marketing innovation. However, investigation of the process by which construction companies select and implement new construction technologies for their projects remains an open question.

Models of the technology adoption process exist outside construction. However, these are not suitable for the construction industry, as construction is widely recognized as a complex system and distinctly different from other industries [31-36]. There is therefore, a need to investigate the current industry practice of decision making in order to provide a systematic framework to assist industry players in facilitating the process, and to hopefully become more successful at utilizing the most appropriate technology in the timeframe available.

The goal of this study is to thoroughly understand the process of technology adoption decision making in construction. Specifically, the research aims to provide a systematic picture of the customers' decision-making practice including their interaction with vendors and the associated vendor activities. The objectives are outlined as follows:

1) to investigate the process used by customers of new technologies as they move from recognizing a need to actually using a new technology;
2) to investigate the interaction and relationships between the activities of customers and vendors;
3) to explore influential factors affecting the process;
4) to identify individuals involved in the process;
5) to formulate the understanding of these activities into a comprehensive framework; 6) to validate this framework empirically against industry practice.

This paper presents the construction technology adoption cube which is used for a systematic multi-phase framework including the commencement of the operation of the technology, following the investigation of possible solutions. The aim of this paper is to understand the methods used to investigate how a customer commits to using a new technology, and how the vendor supports the customer in the process of decision making.

This paper goes beyond previous studies focusing on the individual customer's intention to use a specific technology at a specific single stage [37], by developing a multi-stage framework for understanding the decision process at the organizational level. As well as the customers' activities, the related vendors' activities were investigated, which have been overlooked in previous research [38]. In addition, factors contributing to the adoption decision process are identified and mapped to the framework. Furthermore, the individuals involved in the process are identified.

2. The Concept of Construction Technology

2.1. *Innovation*

Innovation, as a general definition, refers to the actual use of any idea, practice, material artefact, or technology "*perceived to be new to the relevant adopting unit*" Slaughter [39, 40]. Innovation can be "*technological*" or "*organizational*" [41]. This study focuses on technological innovation [42], namely technology that refers to product rather than organizational, one referring to an introduction of advanced management techniques [40].

2.2. *Construction Technology*

'Technology' generally comprises artefacts, the knowledge about them, and the practices of operation of the artefacts [43, 44]. In the context of the construction industry, 'technology' refers to tools, machines, and modifications to them that are used to achieve a goal, perform a specific function or solve a problem [45, 46]. '*Construction technology*' embraces systems, tools and equipment and any combination of resources used in the process of construction from design to demolition [47, 48]. The literature shows that there is a shift from manually operated systems and equipment to "machine-dominated" construction operations [49, 50]. The literature needs to explore and evaluate the way that digital technologies can be utilized in a way to improve productivity and safety in construction projects. A list of technologies that has received attention in the literature include: building information modelling, virtual and augmented reality; mobile and wearable technologies; lidar technology, automated material identification; real time locating and tracking systems; GPS guided plant and machinery [7, 15, 51-54]. In this study, 'construction technology' refers to any tool, plant or equipment used for carrying out physical construction activities, and advanced technology refers to the latest models of such plant and equipment. Examples of construction and mining job-site technologies are:

i) the new Autonomous Haulage System developed by Komatsu Ltd, using high precision GPS navigation system, milliwave radar and optic-fibre gyro technology to control the unmanned trucks on predetermined courses [55];

ii) the universal piling and drilling rig LRB 18 with vibrator type LV 20 with virtual reality and positioning system.

2.3. *Technology Adoption, Acceptance, Diffusion and Implementation*

This paper mainly describes a sample of investigation on the process used by construction companies when involving the technology adoption decision as shown in Figure 1. It demonstrates an example of technology adoption investigation intending to develop a decision framework and contributing to the body of knowledge in this area by delineating the initial stages that customers and vendors pass through up to analyzing collected information [56]. The framework highlights the needs and efforts of customers and vendors, paying attention to the varying issues and constraints of the customer-vendor relationships.

Specifically, the research aims to provide a systematic picture of the customers' decision-making practice including their interaction with vendors and the associated vendor activities. In order to attain the aims, the study followed an exploratory qualitative and quantitative research approach. This approach was employed because it demonstrates the understanding required to explain the process in a broader way and provides a rich insight into the adoption process by investigating the current practice of adoption in the construction industry. Previous works classified the studies in the field of technology adoption into three key perspectives [48]:

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i) the "*socio-economic perspective*" focusing on diffusion theories [57];
ii) the "*managerial perspective*" focusing on adoption considering organization procedures [58-60]; and
iii) the "*psychological perspective*" focusing on technology acceptance [61, 62].

The three perspectives investigate the process at the industry, company, and individual levels respectively [48]. The technology dissemination process involves actively marketing the technology to ensure that a potential customer knows about a new technology [19]. It is different from diffusion and dissemination because diffusion refers to a "*let it happen*" strategy, which is a passive approach [48].

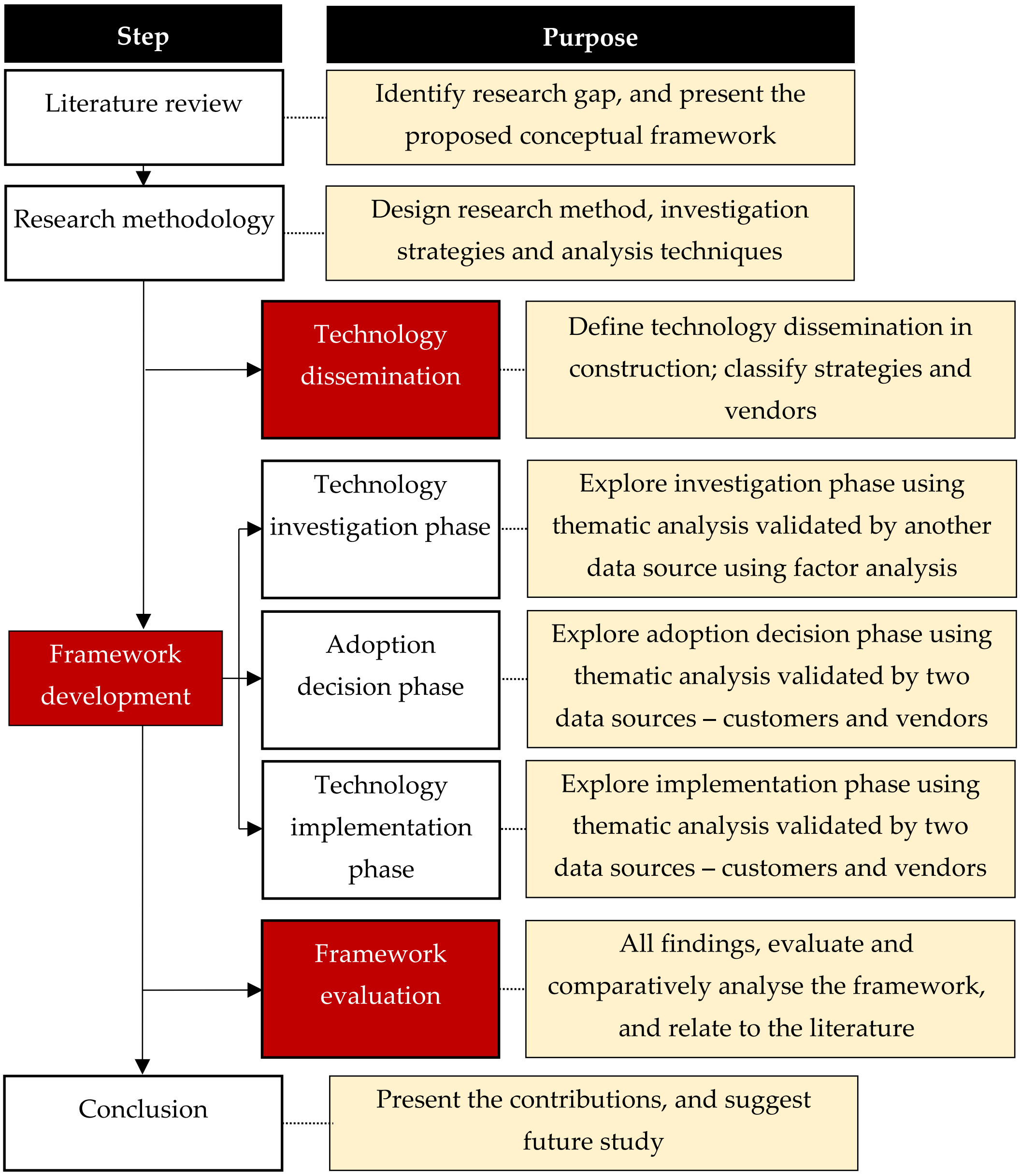

Figure 1. The structure of the study on technology adoption framework development including three main phases of 'investigation', 'adoption', and 'implementation'.

Technology adoption refers to the steps a customer takes in the process through a specific pass to reach a decision to accept using the new technology or reject it. While technology adoption research investigates the customer's organization process at the organizational level, technology acceptance research mainly explores the factors influencing the end user behavior at the individual level [63]. When the technology is adopted, the technology implementation process will be commenced.

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Technology implementation is the process of using the technology as a result of the customer decision, which has already been made [41, 55, 64].

In order to create this picture, it will be necessary to investigate the practices and interactions using qualitative methods. The picture will then be in the form of a framework that groups related activities and interaction with the sequential process of technology adoption. The most appropriate research approach for creating such a framework is to collect data from industry practitioners and analyses this data using grounded theory techniques. Ensuring that the framework is accurate requires rich data; therefore, substantial data sets have been collected from different sources.

3. Research Design

The research employed exploratory and mixed methods to collect and analyze high quality data to achieve each research objective.

3.1. *Mixed research method for construction*

Mixed research methods including qualitative and quantitative methods were chosen to explore the overall structure of the construction technology adoption process. Qualitative methods were specifically chosen rather than exclusively quantitative methods because the literature shows that research is scarce in this area, and so there is a need to investigate and interpret the basic processes occurring, the aim being to produce new insights and understanding of the phenomena concerned [65-68]. The chosen qualitative method is recognized as a useful research approach to determine richer information about the process of technology adoption [34].

3.2. *Grounded Theory*

Grounded Theory (GT) is employed in order to transform qualitative data such as transcriptions and photos into a theoretical or conceptual framework, as it is the best qualitative analysis approach for systematically discovering theory from data [69-73]. GT involves fragmenting empirical data (in this case the transcripts of the semi-structured interviews), adding codes to these fragments, collecting fragments with common codes into categories, and then theorizing based on the interactions between these categories. "*Based on GT, data collection and analysis reciprocally inform and shape each other through an emergent iterative process*" [73, 74]. Collecting codes into categories is also called thematic analysis since it focuses on the themes of the interviews [75]. GT helps identify dimensions of contrast, formulate typologies, present conceptual models, and generate propositional statements [76]. This approach recently has been used in the construction industry, for example, see: [77-80].

3.3. *The methodological cube*

The data from the substantial data sets was collected from semi-structured interviews recruiting both customers and vendors in different regions and then carefully analyzed using a specific procedure of the thematic analysis. As the data was collected from different sources using different formats (transcriptions, photos, etc.), several techniques were employed to carefully analyze the data in appropriate ways, each revealing unique aspects of the process and/or cross-validating each other. In Figure 2, the methodological cube was designed to collect data and analyze them in an innovative way from different dimensions of the complex process of technology adoption. The Cube illustrates the four techniques that were used to analyze the data:

1) cluster analysis of the exhibition data to explore how vendors disseminate their technologies and to classify them based on their dissemination strategies;

2) factor analysis of the exhibition data to explore how vendors support decision makers at the early stages of the adoption process validating the first phase of the framework;

3) thematic analysis of transcriptions of semi-structured interviews to examine the adoption process based on the current best practices of the industry by purposely selected experienced

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participants from both customers and vendors who have recently purchased or sold a new technology; and

4) the analytic hierarchy process (AHP) to prioritize factors influencing the adoption, and the importance of individuals holding various positions in the decision making process. This last is not the main object of the study, but gives more insight about the factors and individuals.

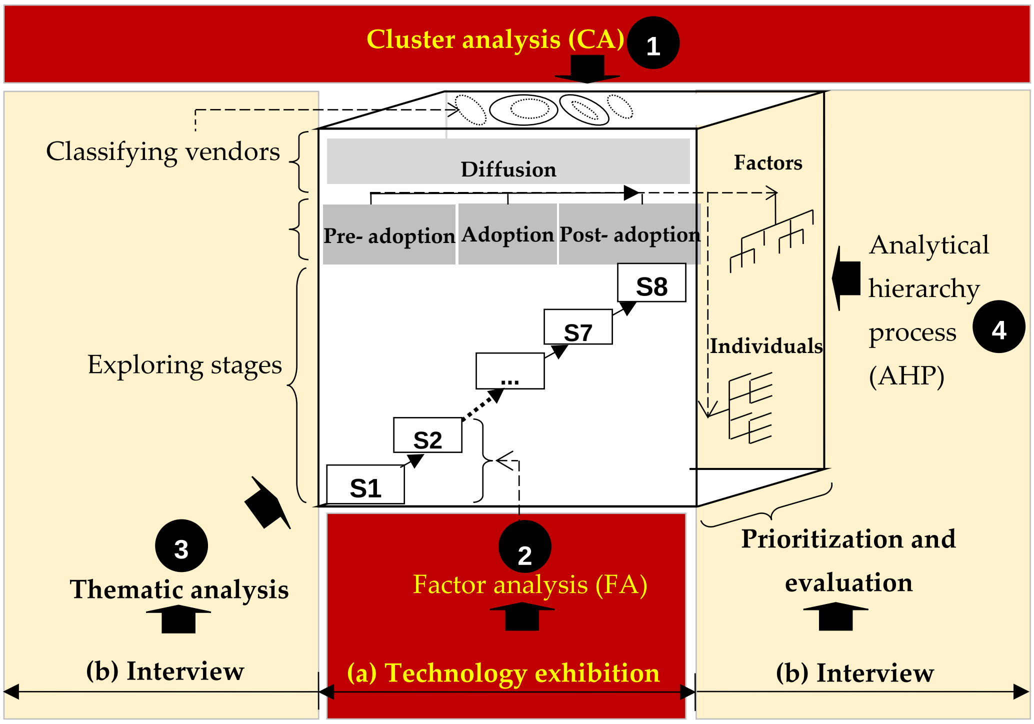

Figure 2. Schematic of techniques employed to achieve research objectives.

Note: The full illustration of the framework (staging process) on the front face of the cube. Pre-adoption, adoption and post-adoption refer to investigation, adoption decision, and implementation phases respectively.

3.4. *Triangulation methods*

The triangulation techniques including a variety of data types and participants are very helpful and important to theories the adoption process, because it increased the broadness of concepts and scope of the theory [70]. The variation and large number of samples prevented observational bias [81]. Utilizing both prolonged engagement and persistent observation in TEs enabled the researcher to get confident in an accurate interpretation of the meaning of data both from TEs and interviews, which increased the credibility of the results [81-85].

- Data triangulation was achieved by collecting data from both sides involved in the process (i.e. customers and vendors); different companies (e.g. family business and corporations); a diverse range of businesses (e.g. pumping and earthmoving); and different regions (e.g. Australia and North America).
- Methodological triangulation was achieved by using different analysis methods (clustering, factor, and thematic analysis), different data types (e.g. photos, voice records, checking structured forms), and from different sources (e.g. TEs or outside the exhibitions).

In order to investigate vendor and customer activities and interactions two strategies were chosen to collect data:

a) Technology exhibitions (TEs) were visited to immerse the investigator in the technology market [19]. TEs are the best environment to investigate vendor and customer interactions, and to record vendor dissemination activities. These visits also enabled the researcher to learn about new technologies in the market, which helped in interpreting some of the interview data.

b) Selective participants were recruited using a wide range of strategies including criterion-chain and comparative sampling methods and interviewed to collect details of the technology adoption process from both the customer and vendor perspectives. Obtaining views from both sides enables cross validation of the findings. Each of the TE visits and sampling methods are explained in the following sections.

3.5. Technology exhibitions

TEs are market places where vendors set up stalls to market their products and customers visit to learn about these products. Customers may discover new technologies at the exhibitions or they may learn new things about technologies that they already know of. Attending these exhibitions enabled the researcher to see how vendors present their technologies and observe vendor customer interactions '*in the wild*'. This provided the researcher with the background and understanding necessary to shape the adoption framework. In order to give more detail to the framework based on data that might not be readily apparent from observing the TEs, experienced participants were recruited to be interviewed. These interviews were conducted face-to-face in order to enable the researcher to take advantage of body language and such cues to direct the interviews into more depth where appropriate [86]. The combination of data resources from exhibitions and interviews provides a valuable originality for this exploratory research, and opens the possibility to triangulate the findings in order to increase the validity of the research [73, 85, 87, 88].

Protocols were designed for collecting data from each of the technical exhibitions visited. This mainly consisted of a consistent set of measures covering the attributes presented by each vendor at the exhibition. This consistency enabled comparisons to be made between exhibitions both within one country and across two continents. Similarly, protocols were designed and tested for the semi-structured interviews to ensure that a consistent data set was collected. Furthermore, in order to fully represent industry practice, participants who had experienced involvement in the process of technology adoption in either Australia or North America (Canada and the US) were recruited. Several participants were additionally recruited who had experienced the process in other countries such as Latin America, Germany, Japan, China, Singapore and Finland, to ensure that the findings do in fact generalize to the worldwide construction industry. The main advantages and disadvantages of the methodology are also discussed with references to the literature in the following sections.

3.6. Selective participants using criterion-chain and comparative sampling strategies

Chain sampling involves selecting extra participants based on recommendations of previous participants to cover gaps in the sample [89]. Comparative sampling [89-92] was used to select participants so that there were major differences between participants on various scales (i.e. smaller and larger companies) and locations (i.e. Australia and North America) so that comparisons could be made along each of these scales. This combination of strategies was used to pick participants from different companies serving a diverse range of businesses such as drilling, pumping and earthmoving. According to Corbin and Strauss [70] variation is significant in theory building because "*it increases the broadness of concepts and scope of the theory*".[37].

Figure 3 schematically illustrates the profile of five experienced participants from Sydney, Melbourne, Nevada and North Dakota that were sequentially recruited from the crane industry. This method of sampling was designed specifically for this study, because the investigator aimed to become immersed in the construction technology market community (e.g. crane technology market), and also aimed to elicit facts rather than individual behavior [93]. This method of collecting data is more robust than the commoner chain sampling technique [89] whereby researchers collect

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'convenience' data based on the availability of participants [94]. This gives significantly greater originality to the study since it provides unique data to explore the technology adoption process.

The participants were recruited using a combination of three strategies: a) a criterion-based strategy; b) a comparative strategy; and c) a chain strategy [90-92]. The combination is designed to select appropriate participants in order to maximize the value and quality of the data from the interviews. For example, one technology that was investigated was advanced mobile cranes. Five participants were recruited based on the combination sampling strategy of 'criterion-chain' from the crane business. Each of these participants was recruited specifically because they had either purchased or sold one or more cranes from a particular crane manufacturer (brand x) with a large market share and it was desired to see both sides of the purchasing operation for the same company.

The criteria used for selecting the participants was that they:

1. Had been involved in the technology adoption process for at least two major purchases of different technology types in the previous three years; and
2. Had been with their present company for at least three years so that they had a good knowledge of their company's procedures.

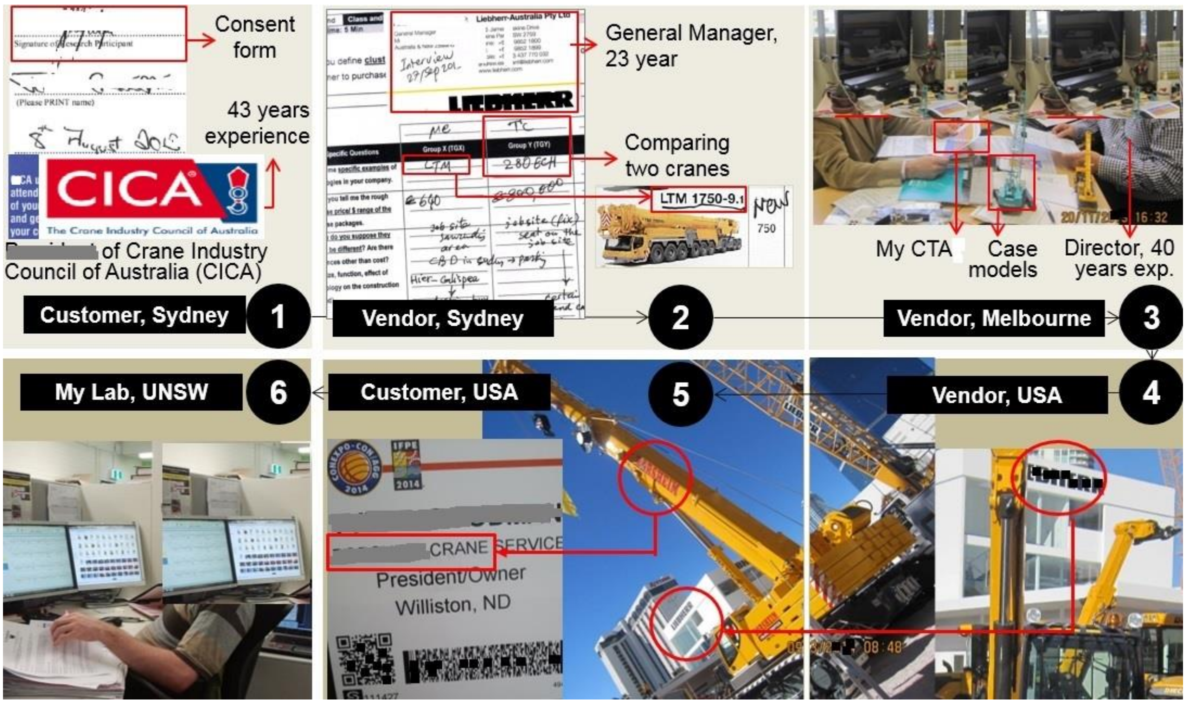

Figure 3. The illustration of criterion-chain sampling from the crane industry to identify the experienced specialists familiar with the crane technology adoption process in Sydney, Melbourne, Nevada and North Dakota.

3.7. *Semi-structured interview*

The semi-structured interview technique was chosen as the best tool to collect data about the vendors' and customers' experiences of the technology adoption process (refer to Figure 4), because it enables the researcher to get in-depth data about the process being studied [65, 95, 96].

This type of interview is a flexible tool that allows the researcher to generate rich data to advance understanding and consequently develop empirically and theoretically grounded argument about the process [67, 96]. However, this type of interview is time consuming both in terms of data gathering and analysis compared to structured interviews. Structured interviews assist the researcher to gather data in a highly structured way. However, they suffer from the disadvantage that they do not allow the investigator to obtain deep understanding of the adoption process, or to explore the cause-and-effect relationship between activities, perspectives and indicators [97]. The problem is that the respondents are forced to choose between alternative choices in structured interviews rather than

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give their own unique opinion. Thus, the respondent's replies may not reflect the 'true' variation in practices [96]. On the other hand, surveys and structured interviews are easier to conduct and create data that is easy to analyze and so they have been used extensively in research of technology adoption in construction (e.g. Alkalbani, Rezgui [98]). Unstructured interviews have the problem that each interview is unique with different content. This prevents the researcher from comparing and contrasting the different interviews, leading to difficulty in generalizing and modelling the phenomena.

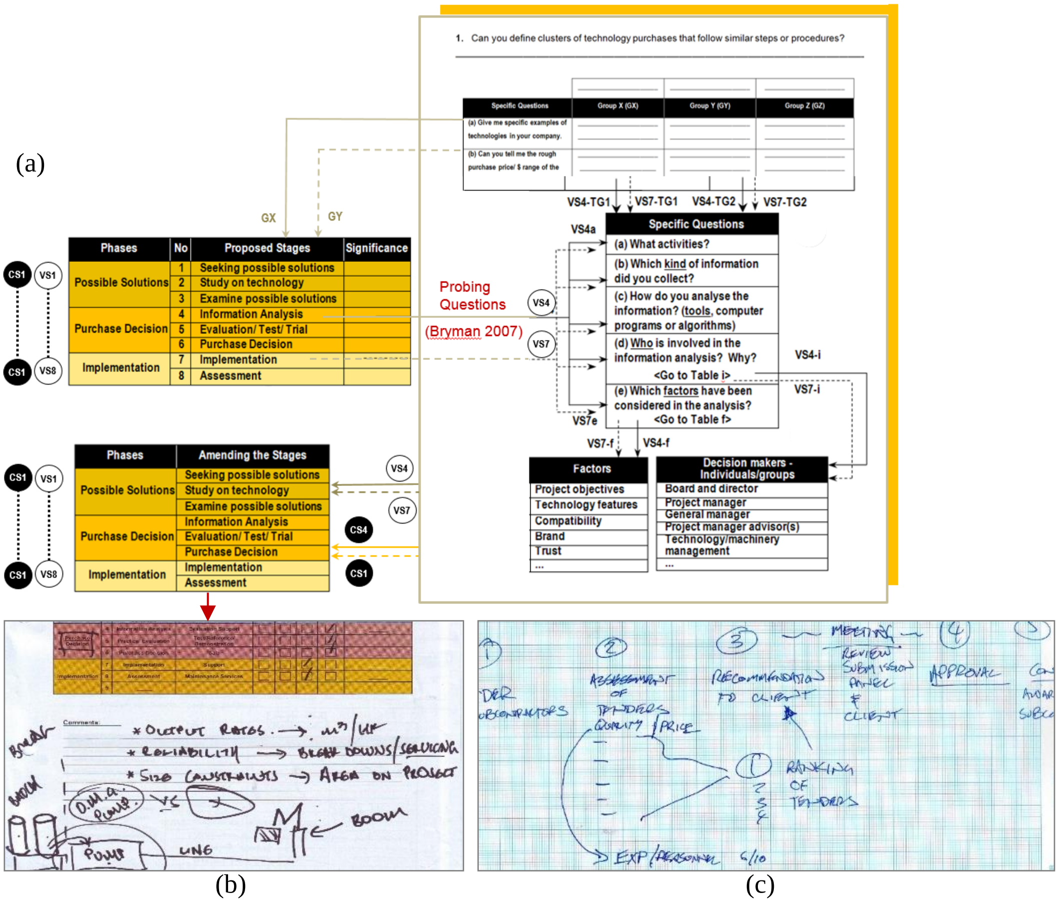

Figure 4. Interview samples: (a) The structure of two types of interviews for customers and vendors. CS refers to customer side, and VS refers to vendor side; (b) A diagram was also collected during the semi-structured interviews, when it was the best way of conveying information. The project manager of a residential tower commented on the stages, and sketched which equipment was used in their project, Sydney; (c) Alternative view of the construction technology adoption process provided by a project manager. The project manager of an educational building sketched the sequential process of adopting a technology in their project, Sydney, Australia.

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in construction (e.g. Alkalbani, Rezgui [98]). Unstructured interviews have the problem that each interview is unique with different content. This prevents the researcher from comparing and contrasting the different interviews, leading to difficulty in generalizing and modelling the phenomena.

The format of semi-structured interviews has been applied in many research studies in construction to investigate a process and the associated related factors such as Agapiou [99], Sarshar and Isikdag [100], Bassioni et al. [101], Redmond et al. [102]; Aziz and Salleh [103], and Samuelson and Björk [104]. For example, Samuelson and Björk [104] investigate factors that affect the decisions to implement different techniques of information technology in construction as well as the actual adoption process. They justify their choice of semi-structured interviews because it allows a wider discussion, while the interview is held around defined areas and the selected theoretical framework. Semi-structured interview is a tool to collect rich data, which is open to the participants' decision about what is important and relevant to discuss. The participants' flexibility can express the process based on the fact rather than agreeing with or rejecting structured questions. Figure 4 shows the structure of semi-structured interviews, which is used in this study. The interview questions were designed based on the proposed construction technology adoption framework (CTAP).

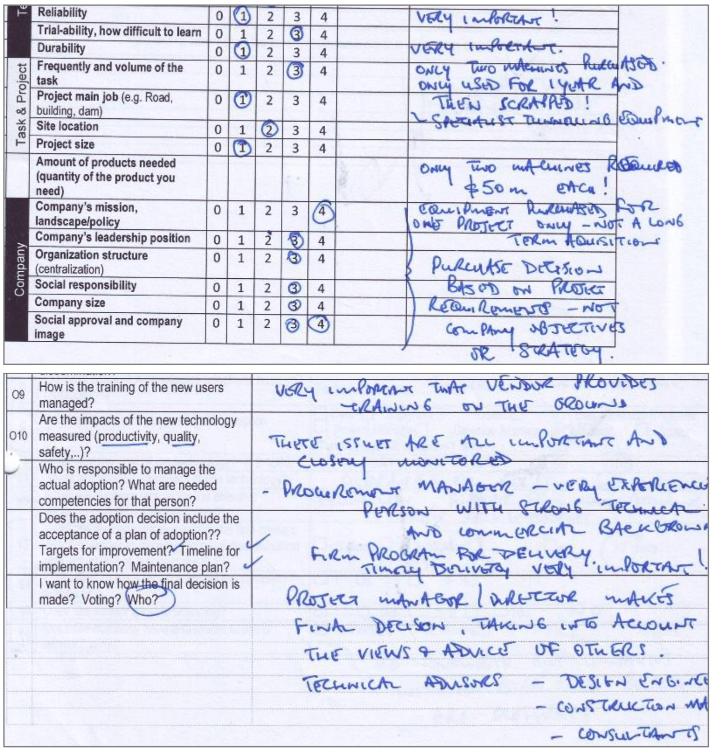

Figure 5. Example of completed questions showing the structured questions to identify key factors influencing the technology adoption process, and a general manager comments on the semi-structured questions.

Step 1 involves the invitation letter, the consent form, the interview agenda and some questions regarding the participant's background. The answers to the background questions were used in selecting who would be in the sample to ensure that it was representative. Step 2 was designed to explore whether there are different adoption processes employed for dissimilar technologies.

Step 3 was designed to ask the participant to examine the proposed stages of CTAP as it applies to their selected technology cases. Step 4 is the main focus of the interview, and allows participants to freely explain each stage of the process revolving around the main topics such as relevant activities and contributing factors in each stage. Step 5 was added to give the participant a chance to reflect on his or her responses regarding the importance of the stages now that they have spent time focused on their own specific details. Samples of participants' responses including their sketches and comments to these steps are shown in Figure 5 and Figure 6.

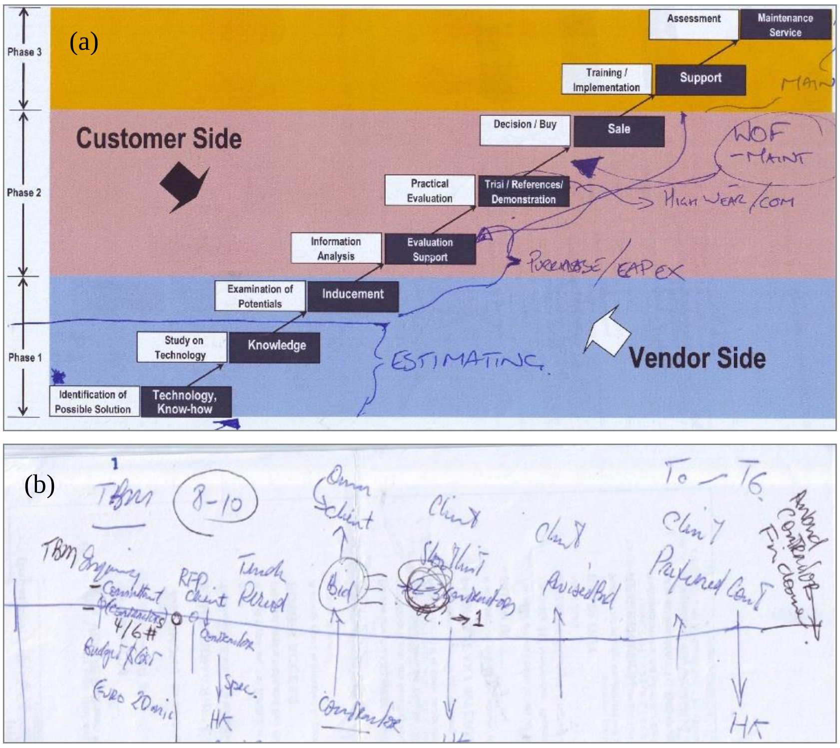

Figure 6. (a) The plant manager of an infrastructure company compared the hypothetical CTAP with their own procedures of expenditure for purchasing a truck mixer and a tunnel boring machine, Sydney. (b) Alternative view of the construction technology adoption process provided by a tunnel boring machine vendor. It shows a sample process sketched by the vice sales managers of a leader company visually explained the process of technology purchase for a tunnel boring machine from the identification of solutions to delivery, Melbourne, Australia.

The data from the interviews are analyzed and used to: a) explore the key stages of '*investigation, adoption decision, and implementation*' phases of the technology adoption process; b) identify contributing factors and individuals involved in the adoption process; and c) classify customers based on their adoption process similarities. Details are provided in the relevant papers, e.g. [10].

3.8. *Questions in the Survey Instrument*

In order to investigate the construction technology adoption process, semi-structured interviews were employed [65, 70, 96]. Participants were asked to compare the decision process for two different technologies that they had been involved in purchasing or selling. In order to ensure that the technologies were significantly different, participants were first asked to identify two different technology groups that they had been involved with purchasing and/or utilizing. They were then asked to select two different technologies, one from each group, as case studies for the interview.

These participants quotations were separated into a sub sample in 'NVivo 10' for analysis. NVivo is a powerful workspace for qualitative analysis, which enables parts of interviews and the ideas contained there to be tracked without losing access to the source data.

In order to generalize the technology adoption process across countries and cross-validate them, it was checked that the sub sample included sufficient participants from the construction industry. Samples of supplementary data are provided in Figure 7.

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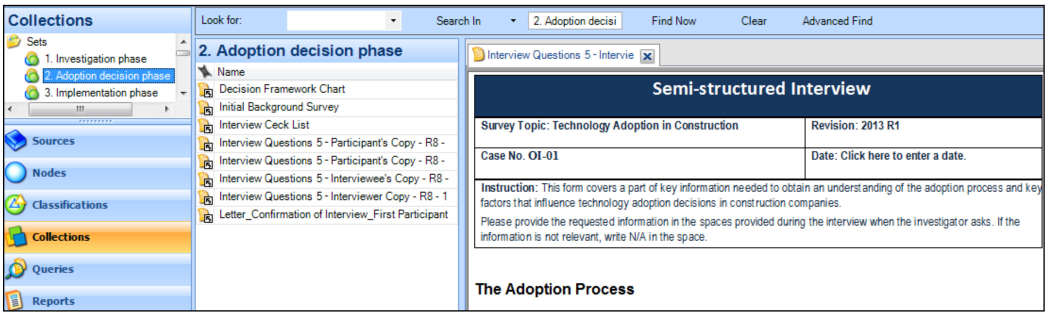

Figure 7. Creating the data set for technology adoption phases including the participants responses.

The data set was systematically analyzed in two iterations. First, different stages of the process were identified, and the framework developed. Second, both the contributing factors and the individuals who were involved in the adoption decision process are discussed.

3.9. *Exploring the Process*

In this section, the transcriptions from the interviews are examined using thematic analysis techniques [105, 106] in order to identify themes representing the stages a customer passes through after technology investigation. The themes are identified based on customer and vendor activities and are used to structure the adoption decision framework.

Figure 8 shows the flow chart of the research method. The first five steps develop and validate the framework. Next, all of the findings are merged to define each stage of the framework. Finally, the factors and individuals involved in the adoption decisions were identified.

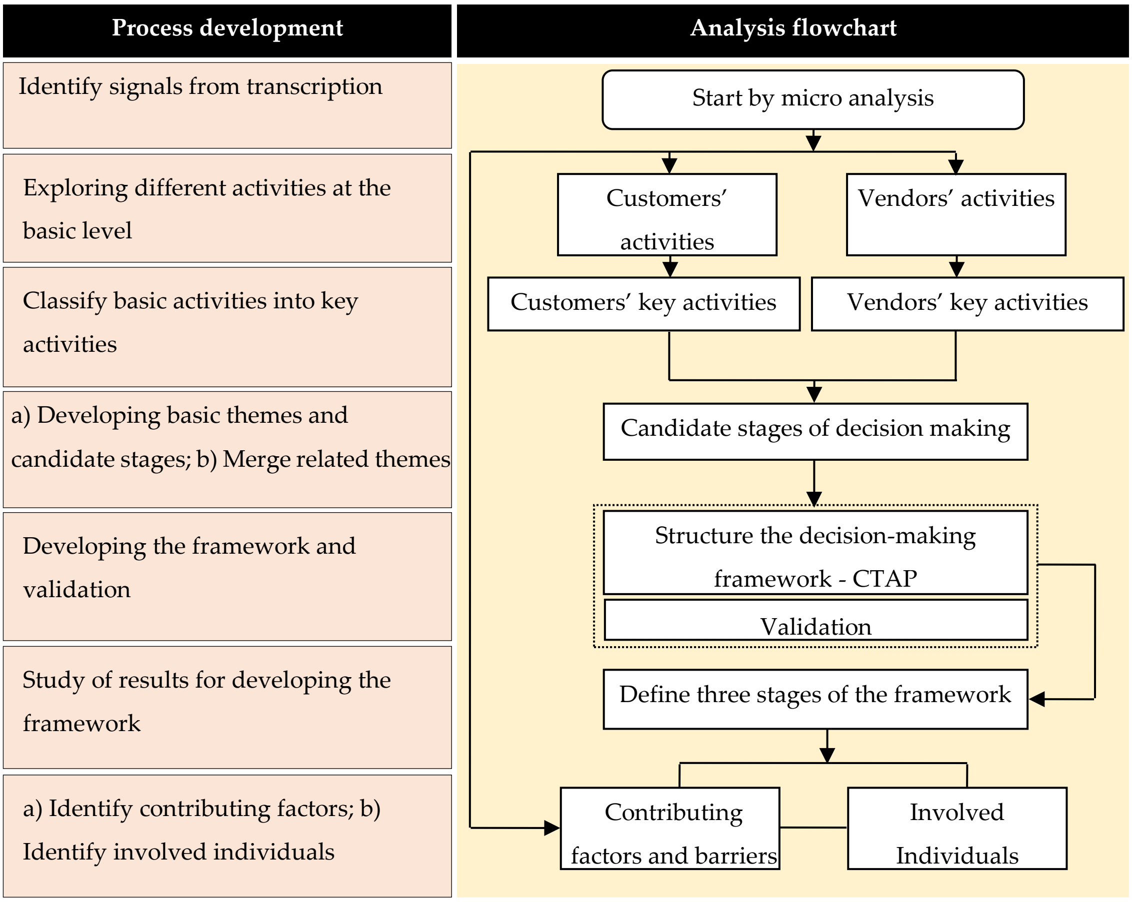

Figure 8. Systematic analysis flowchart to explore the CTAP framework.

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In Step 1, the transcriptions are coded in a systematic way as shown in Figure 9. In Step 2, relevant passages are linked to the nodes related to customers' and vendors' activities, where each child node represents one core idea. In step 3, all child nodes are allocated to new parent nodes respectively and sorted into basic themes. In Step 4, a web-like map is developed reflecting child-parent relationships and nodes, e.g. [10]. In Step 5, the candidate themes were closely examined in order to ensure that they did not overlap. The examination resulted in three coherent patterns representing the key activities that make up the adoption decision process.

3.10. Micro analysis and coding data

The transcripts were broken down into smaller parts called passages in order to classify and create meaningful concepts [107] from which appropriate themes are extracted. In order to analyze the data without missing useful material [108, 109], six criteria were used to choose passages. This involves selecting:

1) words and sentences describing any aspects of the process [70], an example is shown in Figure 9;
2) any incidents describing the process, to discover patterns and contrasts between groups that might be used ultimately to evaluate the process investigated [110];
3) causal sentences with signal words (e.g. because, reason, do you know why) that will be used in the next step of the analysis to identify relationships [111];
4) preceding and sequential statements that might lead to a process (e.g. before, after, then, the next stage);
5) any new idea or sentence related to the adoption decision [110];
6) paying attention to the participants' use of special terms as *in vivo* codes [110]. These codes are created to ensure the concepts stay close to participants' own words, because participants capture a key element of a phenomenon that is being described [112].

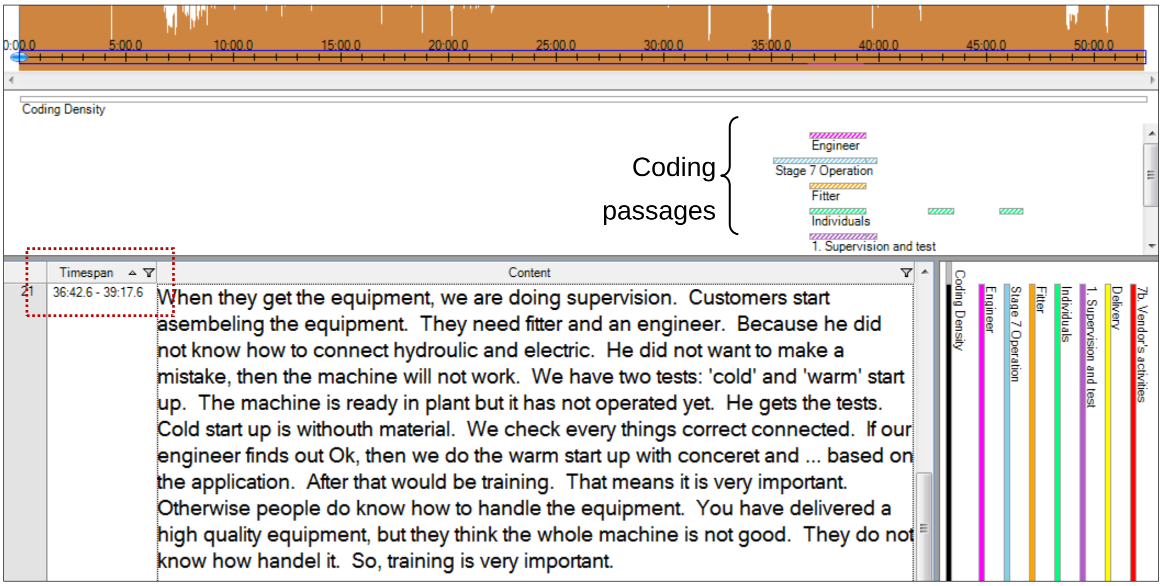

Figure 9. A sample of coding analysis on the transcriptions in the created data set on ''NVivo 10'.

These criteria are used to carefully investigate passages using line-by-line analysis, a process called micro analysis [71]. Each passage that fits one of these criteria is associated with a child node that represents the core idea.

In order to increase the reliability of the results, immediate analysis of the data took place by writing memos concurrently with the coding. Charmaz [110] recommends the memo as a useful technique for interpreting results. "*Memos are the theorizing write-up of ideas about substantive codes and*

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their theoretically coded relationships as they emerge during coding, collecting and analyzing data, and during memoing" [75].

3.11. Create activity and factor nodes

At this point the passages that indicated a part of the adoption process or a related activity (e.g. training, delivery and commissioning) had been identified by applying the six criteria from the previous section. In the next step, these passages were assigned into relevant child nodes, a process referred to as coding the passage. Each of these child nodes represented one activity related to the purchase decision. In order to increase the consistency of analysis, active words such as 'I go', 'I try', and 'we ask' are considered as signal words for coding the passage. If a node relevant to the passage did not exist, a new node was created. Figure 10 also shows the Fishbone diagram including all factors proposed at the beginning of the study. The factors which were verified by participants, were assigned to the nodes and used in this study (see Figure 12).

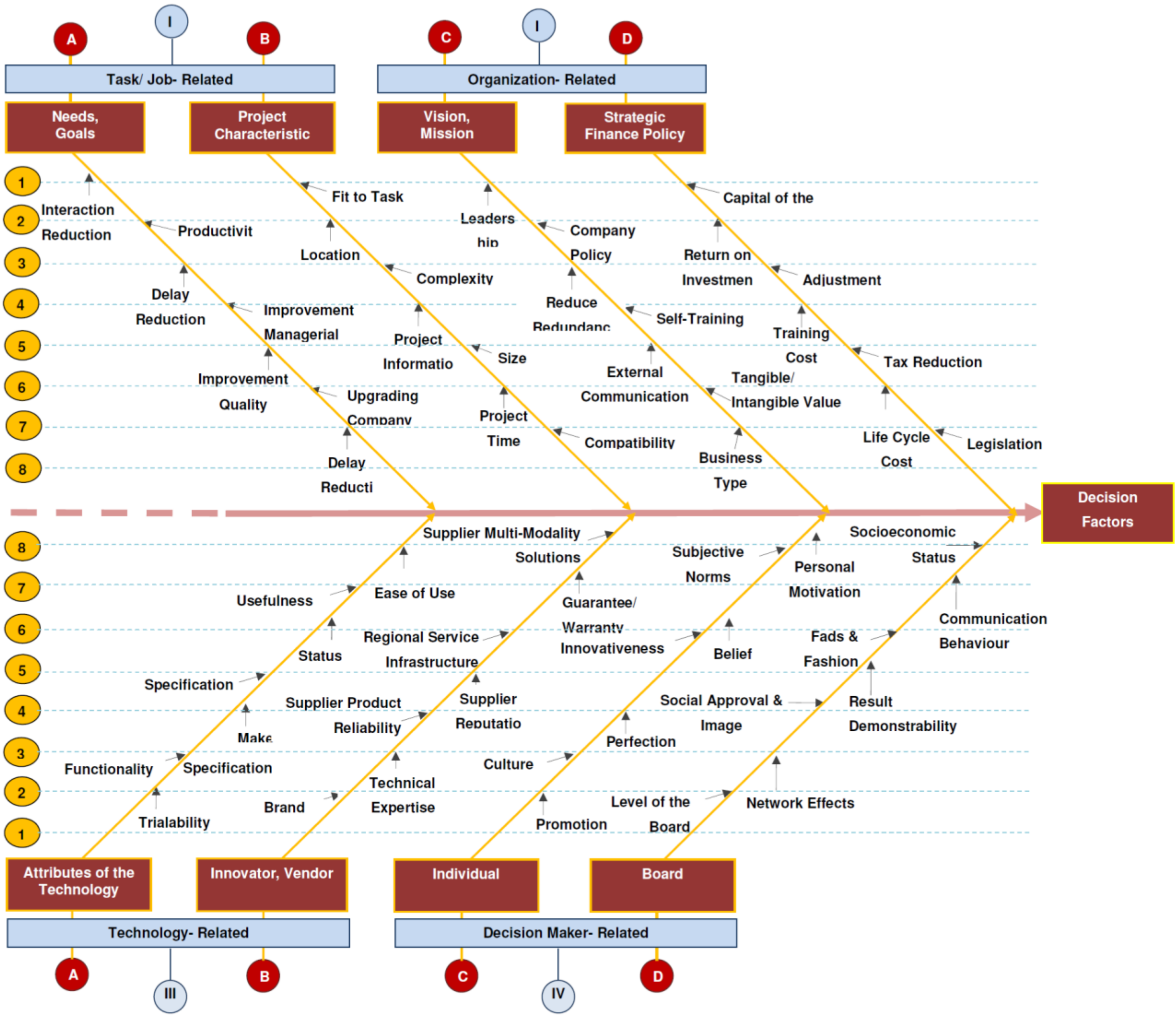

Figure 10. Fishbone diagram technique implemented to categorise factors from the literature review related to Information System Acceptance.

4. Results

The purpose of the interview was also to identify the individuals assisting in developing the decision makers' network. Previous literature indicates that the only individuals involved at this stage whose opinions are sought regarding the factors in the previous section are top managers. Top managers will then support the end users with training and rewards. This literature mainly focused

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on user behavior in technology acceptance from a psychological perspective in terms of usefulness and ease of use. However, during the interviews it emerged that engineers, operating crews and fitters are also consulted during the purchase decision making process. Results of coding transcriptions and the questions about individuals who were involved in each phase are presented in this section.

Some participants pointed out that individuals from the production level may not be available when the purchase decision is being made. In this case, the company was advised by those who have performance expertise with similar technology use for similar tasks. For example, they ask advice from a plant manager of a similar project when they are going to buy a tunnel boring machine (TBM). When the production team are appointed after technology delivery, they were responsible for any necessary customizing or upgrading of the technology.

Additional coding shows that there is a stage in the framework that refers to making a decision to commit to the technology use. The interview shows that the two previous stages, 'analysis' and 'substantiation', are the basis of the decision. For example, a customer describes that:

"evaluation of support is the most critical part. That will make or buy the sale. The sale will come later; it will come automatically".

The main activity in this stage is that customers negotiate with at least two vendors, choose a technology, and commit to use it by contract. Before any commitment, the customer and the vendor would negotiate in order to clarify and modify specifications and details about the proposed commercial terms and conditions. In addition, the customer negotiates with the candidate vendor about the price based on the competition's price. For example, an experienced vendor describes:

"[In this stage,]he knows that he wants to buy [brand A], and he gets the price. The pricing difference between [brand A]and [brand B], for example, may only be marginally different. There might only be, let's say $20, 000 in it. [...] So, he will go back to the [brand A] bloke and he will say, 'This is the quote from [brand B]. He is cheaper than you'. And he will haggle with the price. [The brand A vendor] then says 'Well, I will I match that' or he says 'I cannot do it.'"

Based on the negotiation, the customer and vendor will finalize the contract. Thus, the customer has selected a particular technology to adopt. However, whether the customer continues to use this particular technology long term will depend on how it and the vendor performs once it has been implemented. It is important to focus on the implementation process in order to understand how the adoption process will be continued and assessed. The next sections will examine the factors used in the decision and the roles of the people involved.

Figure 11 shows that the participants were defined (using AHP analysis), who was involved in the adoption decision processes of analysis and making the final decision. Previous literature indicates that the only individuals involved at this stage whose opinions are sought regarding the factors in the previous section are top managers. Previous literature has only discussed the role of top managers in this process and has been silent regarding the involvement or lack thereof of other workers in different phases of the decision making process separately [113, 114]. For example, Peansupap and Walker [113] identify that top managers initiate the adoption process, support and encourage end-users to use ICT. This study identifies other relevant individuals involved in the decision phase of the adoption. The interviews show that project managers have a critical input in the decision. For smaller purchases, they will have the authority to authorize the expenditure; for larger purchases, they will need to obtain approval from higher in the company, but the decision starts with them. In making the decision, the project manager will normally collect the opinions of operators and engineers (e.g. mechanics) for evaluating the technology and obtaining suggestions about technology attributes and aspects of operation. A company manager states "*These guys [pointing to operators] give advice, the guys that run the equipment*." Managers understand information systems as most of them have the basic skill of using internet and software, and also they could easily imagine the output of the system based on experience. However, they do not necessarily know how a new construction technology (e.g. crane or tunnel boring machine) operates in different site conditions. This makes the decision difficult, as top managers may have limited skill and individual knowledge about such an expensive expenditure.

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The interviews show that for smaller companies the owner might be a machine operator as well. However, they would still consult the expected future operator of the specific machine about to be purchased about the decision. If the operator of that specific machine is not available (e.g. project is not yet started), or has not enough experience in a specific type of technologies (yet), the company recruits an experienced individual outside the company. A participant states:

"[We make the decision] based on experience; if you find someone that is an equipment person, that has been in the field for many years and has been around different pieces, you get his knowledge: 'what have you experienced has been the best one for this?'."

The interview shows that project managers also analyze financial and technical information of their technology choices using a comparison matrix to pick two of three technologies and vendors. A vendor describes:

"Normally, the purchasing guy takes three offers. This is the rule. Then he checks the three offers with the [project] manager, and says can we take all three? Do you have any problem if we take three? Or should any company [be] deleted because of technical competency (let's say technically is not good)? and the manager says, for example, 'from these three companies we took only two.' Then they invite both companies."

Some owners described getting advice from several individuals at the company to make the decision, because *"Somebody else's decision might be better"*. In fact, the finding shows that the decision is a result of interaction and consultation with individuals in different positions (top, middle, and production levels) from the corporate head office, project and production levels, including both technical and financial discussions. For example, a contractor states that *"Everybody [of our management team of five] is involved in the decision."* Another description of the decision makers' arrangement is "*The decision is a collaboration of all the ideas, of all the thinking, of all the people in our company*."

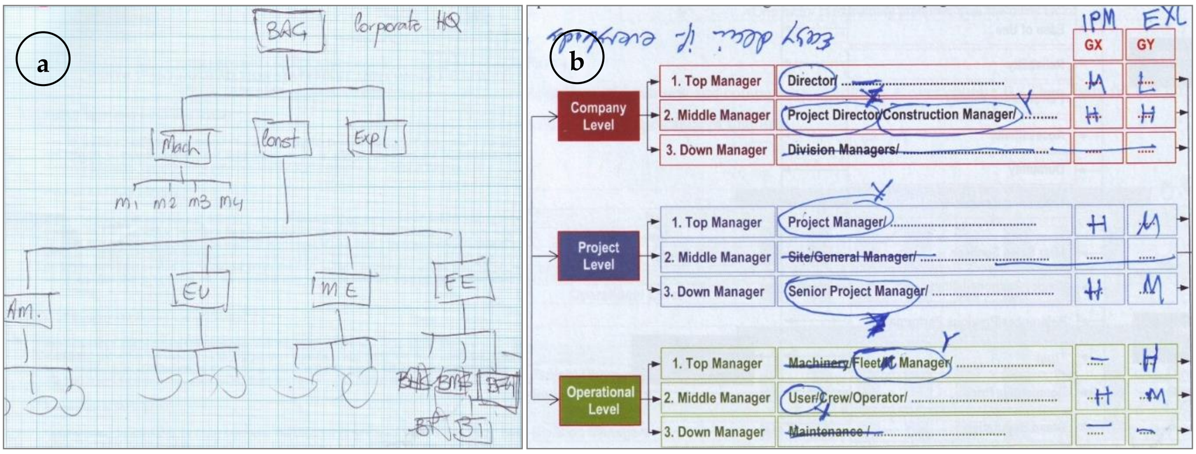

Figure 11. (a) A sample sketch of an organizational chart to identify who were involved in the technology adoption process in the participants' company. This is a typical hierarchy indicating the parties involved in the technology adoption process. (b) The participants explained the people involved in the adoption decision to be the base of the AHP questionnaire (GX and GY refer to two different technology groups). This structured diagram was developed from (a) and other responses.

Note to Figure: GX and GY refer to group X and group Y technologies. This is a sample of comparison based AHP analysis enabling the researcher to compare to what extent mangers influence the decision for each type of technologies.

The results of coding transcriptions and the questions (see Figure 9) about factors and individuals who were involved in the decision phase are presented in the Table 1.

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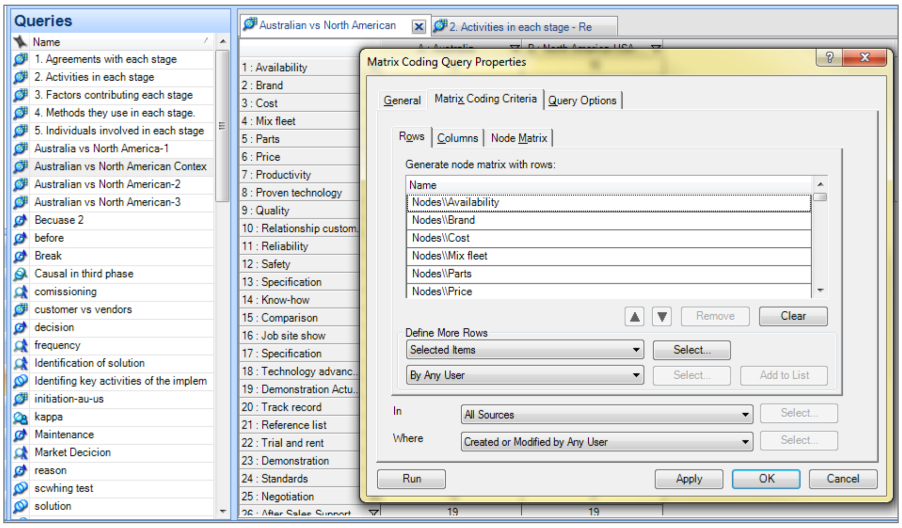

Figure 12. Applying the 'matrix coding query' on the stored data including created Nodes in 'NVivo 10' for comparing Australian and North American contexts.

Note: Matrix coding query is a tool in 'NVivo' for comparing items to display the results in a table or a matrix.

Table 1. Individuals involved in the adoption decision phase.

Node	New role	Confirmed role
Top manager		✓
Middle manager (project or construction manager)		✓
Production manager (e.g. fleet manager) and operators	✓	
Financial manager	✓	
Engineer (mechanical, electrical)	✓	
Project manager advisor	✓	

The participants were also asked to define who was involved in the implementation phase. The purpose of this question was to find who might influence the adoption decision by providing feedback about operation and maintenance of the technology which helps to identify the individuals assisting in developing the decision makers' network.

Table 2. Individuals involved in the implementation phase.

Node	New individual	Confirmed individual
Top manager		✓
Middle manager (project or construction manager)	✓	
Production manager (or/and fleet manager)	✓	
Fitter	✓	
Engineer (electrical or/and mechanic)	✓	
Crew (and/or operator)	✓	

Top managers will then support the end users with training and rewards. This literature mainly focused on user behavior in technology acceptance from a psychological perspective in terms of

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usefulness and ease of use. However, during the interviews it emerged that engineers, operating crews and fitters were also consulted during the purchase decision making process. Results of coding transcriptions and the questions about individuals who were involved in the implementation phase are presented in Table 2.

5. Discussion and Future Directions

This section is divided into two main parts. First, it discusses the findings of this exploratory study; and second, more importantly, it provides a framework for future studies. To do so, Figure 13 illustrates the overall CTAP, based on the analysis method utilized, and refers to the objectives of CTAP studies. The major elements of CTAP are shown in Figure 13 including dissemination, investigation, adoption and implementation and are reviewed as follows.

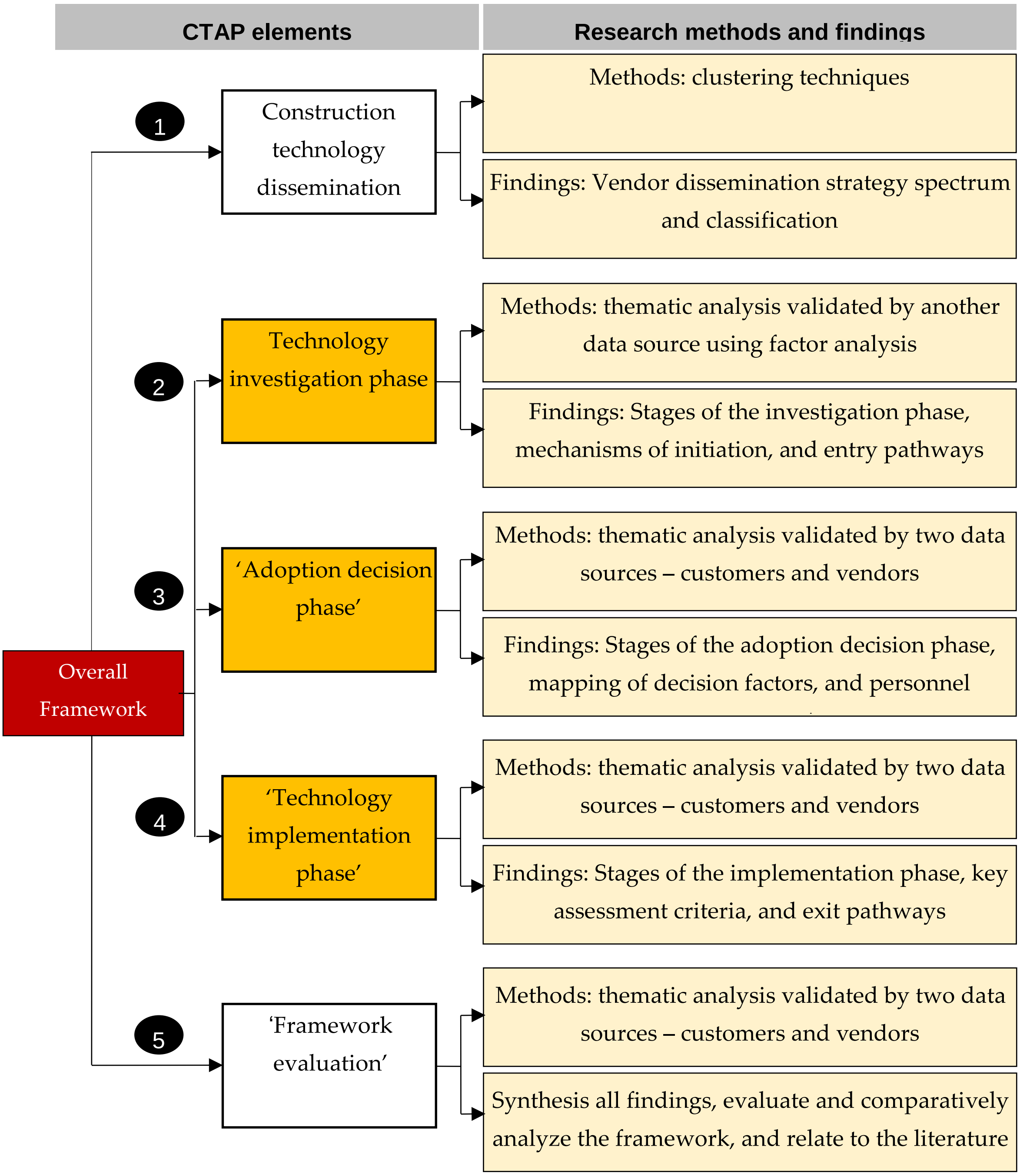

Figure 13. A summary of research methods, findings and achieved objectives.

5.1. *Technology 'dissemination' strategy patterns and vendors classification*

This section discusses the distinction between 'diffusion', previously studied in the literature, and 'dissemination' in the construction technology market, referring to the proactive process of vendors' activities for promoting their technology. The study suggests there are clusters of vendor strategy patterns that different vendors use to a greater or lesser extent, forming a spectrum of vendor business behaviors. Future studies should discuss to what extend physical appearance of the product of vendors dissemination booths can contribute to the adoption process. Furthermore, how technology demonstration can attract more customers and contributes to the adoption process. The interviews showed that vendors were actively involved in the adoption process and must be considered as a part of the adoption process for a more accurate prediction of technology adoption, which has been ignored in the construction literature.

5.2. *The 'investigation' process*

The interviews pointed out that the first phase, namely the pre-adoption process might be relevant to the company readiness to use a new technology. This stage covers up to the point where the customer was in the position to shortlist the number of technology options and linked to needs and objectives. This stage might be relevant to: a) the identification of possible solutions; b) knowledge acquisition; and c) comparison of possible solutions. These three main elements should be mirrored by vendor activities which respond to potential adopters by offering: a) solutions; b) knowledge; and c) inducements. Conducting further analysis may show different applications of CTAP showing how customers start the process from different pathways comprising various mechanisms related to identification of need.

5.3. *The 'adoption decision' process*

The interviews show that the decision stage can be the complex part of the process referring to the point where the customer makes the decision to purchase a new technology. This phase of the CTAP may consist of: a) analysis; b) substantiation; and c) final decision. These three stages should be mirrored by vendors' corresponding activities which respond to potential buyers by offering: a) specific information about their technology; b) trial demonstrations or access to referees; and c) contracts of sale.

5.4. *The 'implementation' process*

The interviewees also discuss that the third phase of the CTAP covered from delivery of the technology up to the point where the technology either became part of the customers normal operations or was rejected. Following a similar procedure of thematic analysis employed for the previous phase, the findings present the original hypothesis that the implementation process consists of: a) commencement of operation; b) maintenance setup; and c) assessment. These three stages should be mirrored by vendor activities which respond to potential adopters by offering: a) delivery and training; b) repair support; and c) feedback mechanisms. Further analysis of the interview data should distinguish four pathways that a customer would follow depending upon the assessment outcome [10].

5.5. *The 'CTAP Cube'*

The combination of this study and previous findings resulted in developing the CTAP cube representing a systematic adoption process. The CTAP cube was assembled by combining the three main phases and all relevant factors and individuals involved in the process. Applications of the CTAP for different technology types should be investigated.

The CTAP cube shows the associated factors and individuals, and also groups of decision makers. The relative importance of assessment criteria factors and personnel involved in the adoption process are also should be specifically evaluated. The findings go beyond previous studies, which

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primarily consider one type of decision maker, by exploring different key themes referring to '*pioneers vs followers*', '*corporations vs family businesses*', and '*Australian vs American buyers*'.

The figure shows that the next step is to identify factors contributing to the adoption process and people involved in it. This study identified the level of importance of each person.

This paper refers to the multi-stage framework assembled by the combination of the three phases explored in the previous papers. In addition, applications of the CTAP were discussed previously to accurately predict the adoption process for each technology type.

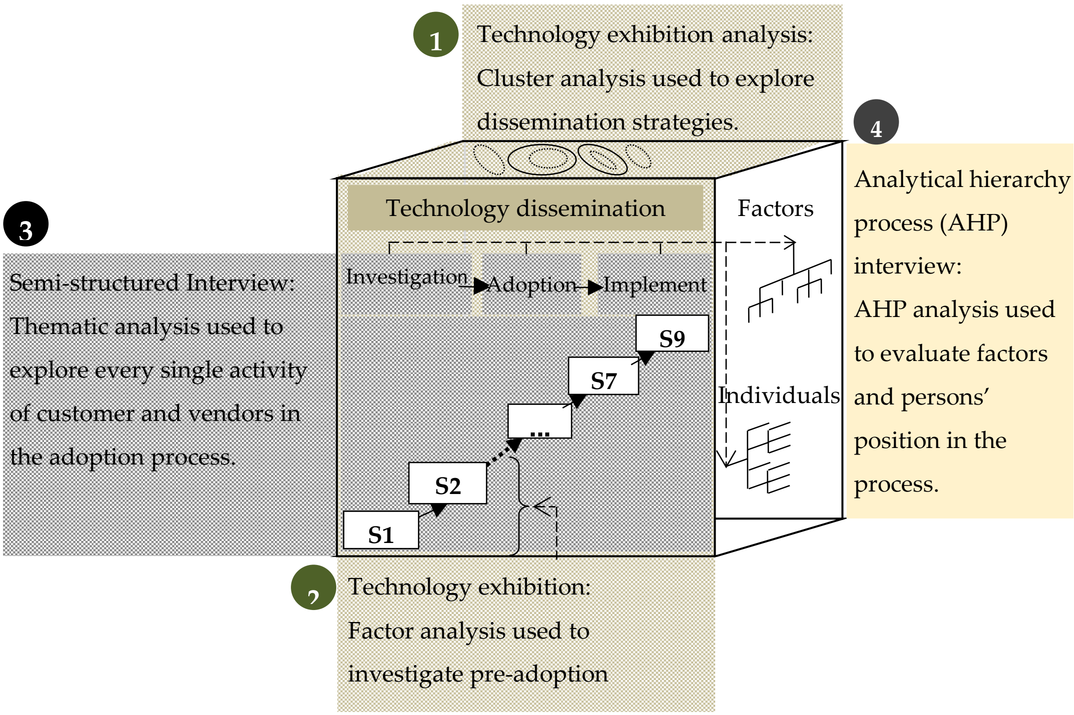

Figure 14. Schematic illustration of the methodological Cube, showing the relationship between objectives and contributions. The data was entered into four software programs: *Matlab, SPSS, NVivo, and Expert Choice.*

Technology exhibitions and cluster analysis

The first face of the cube refers to technology exhibition analysis using cluster analysis. Technology exhibitions have been overlooked for investigation in construction, although such a multibillion-dollar business has received an intensive attention in the literature outside construction [e.g. 115, 116-129]. Technology adoption studies can take advantage of technology exhibitions by immersing [130] in technology exhibitions in order to test the hypothesis that vendors proactively take a variety of dissemination strategies to support customers in the technology adoption process in the construction industry. The strength of the immersion is reinforced by the inherent ability to use the more flexible contextual data from technology exhibitions to lead an exploration of dissemination strategies. Such a flexible first-hand data covering vendors with various businesses who are disseminating a wide range of technologies is not susceptible to being collected from other resources in the construction industry.

A large number of samples from technology exhibitions would enable the investigator to apply quantitative analysis techniques: Hard (e.g. hierarchical and k-means) and fuzzy (c-means) clustering techniques [see: 131, 132-134] were used. The techniques are known powerful tools that were appropriate to examine the hypothesis of dissemination strategies' pattern recognition by classifying vendors and customers based on their strategies, because the results of each singular analysis method cross-validates the other one, and additionally validity tests the partition coefficient (PC) and the classification entropy (CE) were verified by the fuzzy methods.

Technology exhibitions and factor analysis

The second face of the cube refers to technology exhibition analysis using principal component analysis. The principal component analysis [see: 135, 136-138] technique is the most appropriate technique to test the hypothesis of distinct stages of adoption processes, because it is an appropriate tool to find hidden patterns of activities of vendors in the samples.

Semi-structured interviews and thematic analysis

The third face of the cube refers to semi-structured interview analysis. The flexibility of the analysis allowed the interviewer to narrow down the questions when participants were senior with a specific experience of the adoption process [139], particularly when it was about unique technologies such as tunnel boring machines. The researcher asked additional questions to fill the gaps in the collected data. This flexibility was also valuable to allow questions about new related themes that came up in the interviews and were not proposed in the framework, such as 'maintenance set up' and 'pioneer' themes. The open-ended questions allowed the practitioners to describe the process using their own words and special terms (e.g. '*crane roadability*', 'dry and wet test') that were labelled later in the data analysis as *in vivo* codes [110]. This enriched the findings by keeping them close to participants' own words, because participants "*captured a key element of a phenomenon*" that is being described [112].

Much research in the innovation adoption field (e.g. information systems, new materials and administrational technologies) was used in questionnaire surveys [e.g. 37, 140, 141, 142] and all suffer from the disadvantage that they did not allow the investigator to explore new activities in such a context-specific topic and the cause-and-effect relationship between them. Semi-structured interviewing has recently been used in construction as a flexible tool to collect rich data [e.g. 34, 102, 143, 144, 145]. However, often small samples were used preventing exploration of any patterns of similarities or differences, and so suffer from observational bias in the sample [81].

A specific procedure of data analysis based on coding and thematic analysis, was used because they allowed recognition of commonalities and discernible themes to constitute the framework [68, 105, 106]. The procedure enabled the researcher to break down the data to identify constructs first, and then the framework structured (bottom-up) rather than considering the whole framework and using data to prove it. The procedure was separately applied to both customer and vendor data (i.e. transcriptions) and corresponding themes were cross-validated with findings of the analysis. The thematic map [146] exercise revealed the richness of the data's structure and its underlying patterns.

Structured interviews and AHP analysis

The fourth face of the cube refers to Analytical hierarchy process (AHP) interview analysis. AHP is a powerful multi-criteria analysis technique assisted in evaluating the factors and people involved the adoption decisions. Using this reliable technique [147-149], the contributing factors to the decision were ranked in order to evaluate the importance of factors and individuals, who are involved in the adoption process.

Cube development

Overall, the combination of the four above-mentioned faces gave significantly greater originality to the CTAP cube analysis, since it provided extremely valuable data to explore the theory grounded in such rich data. For example, the technology exhibition visits gave the opportunity to identify experienced participants from both customer and vendor sides by applying a combination of sampling strategies (e.g. chain sampling, refer to Figure 3). Identifying such eligible people who were recently involved in the adoption process would not be possible using other strategies. Such a combination of the purposive sampling increased the transferability of the research findings. The large sample of data from different sources drastically increased the external validity [92].

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The concept of the CTAP cube enabled the researchers to apply both data and methodological triangulation techniques [150-152] in order to attain validity of the results by data and methodological triangulations.

5.6. Triangulation techniques and Validation

The triangulation techniques including a variety of data types and participants prevented observational bias [81]. Utilizing both prolonged engagement and persistent observation in TEs enabled the researcher to get confident in an accurate interpretation of the meaning of data both from TEs and interviews, which increased the credibility of the results [56, 81-85].

Achieving such benefits (as discussed) from the CTAP cube gave a larger originality to the study by a higher level of reliability and validity than each singular method. According Abowitz and Toole [89] using mixed methods increases reliability and validity of the data and provides greater confidence in tests of the hypotheses compared to singular methods. However, the method utilized for the study by prolonged engagement to the technology market was costly, and took four years of persistent investigation. It involved travel to five cities in two countries to collect data, transcribe voice records, edit transcriptions and coding thousands words to identify themes. This was coupled with the study of many exhibition papers, reports, catalogues, and photos, and entering data to four software programs, Matlab, SPSS, NVivo, and Expert Choice. That is why utilizing such methods to obtain substantial data sets are neither common nor feasible in construction [89], and researchers collect "*convenience*" data [89] based on the availability of participants [94]. For example, Rahman [141] published the result of a survey on barriers of an innovation adoption (i.e. modern methods in construction) in a credible journal in construction while a reasonable response rate was not achieved. Seventy-five percent of participants in his sample had never experienced any type of modern methods in construction, and the average of participants' experience in the sample was 5.67 years as reported, showing that most of them were young participants. These participants could not disclose the actual barrier as they had not experience it, while the researcher could employ a mixed method approach and obtain other sources of data to triangulate in on the "*true*" result [89].

As a final validation of the findings, the developed CTAP has been discussed with industry experts by showing them the framework. In the remainder of the interviews, the participants' views about the developed CTAP were sought. The results of the industry experts were also used for validity purposes, and added more information about the implementation process. This technique of validity has already been used in different forms in construction [153-155]. For example, Lucko and Rojas [153] suggest that interviews with industry experts allow a richer feedback, as the researcher can clarify and extend individual factors ad hoc in a semi-structured manner [156].

Table 3. A summary of objectives accomplished.

Description	**Limitations and/or future direction**
To investigate the vendors activities to expose their technology	To profile them based on their dissemination strategies in different contexts
To explore influential factors and barriers affecting the process	To examine the identified factors in different contexts
To identify individuals involved in the process	To investigate the interaction and relationships between the activities of customers and vendors
To formulate the understanding of these activities into a comprehensive framework	To investigate the process used by customers of new technologies as they move from recognizing a need to actually using a new technology

Each face of the cube shows an achievement of the study including: vendors' dissemination strategy patterns, vendor classification, and developing the dissemination framework. The objectives achieved are shown in Table 3.

The main method for proving the hypothesis of the staging process was to utilize the thematic analysis that systematically explored each possible stage of the process (for each phase). The

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exploratory analysis revealed details of customer-vendor activities, relationships and interactions that resulted in modifications to the hypothesized stages in terms of naming (to appropriately reflect the current practice), demarcating the boundaries of each stage (to represent distinctions), and identifying customer and vendor activities separately. The CTAP cube assisted the researchers to cross-validate the findings by:

- Using different data sets from both sides involved in the process (i.e. customers and vendors); different companies (e.g. family business and corporations); diverse types of businesses (e.g. pumping and earthmoving); different regions (e.g. Australia and North America).
- Using different analysis methods (clustering, factor, and thematic analysis); different data (e.g. photos, voice records, checking structured forms); and from different sources (e.g. TEs or outside the exhibitions).

5.7. *Statement of CTAP cube novelty*

The original contributions of the CTAP cube analysis lie in its combination methods of data collection and analysis of extensive empirical data to establish a scientifically sound understanding of technology dissemination and adoption processes. The data covers a wide range of construction technologies rather than focusing on a single technology case study. The study is different to other studies as it considers customer-vendor activities and interactions instead of previous studies that focused on only the customer. In addition, the findings apply to organizations (i.e. technology adoption) as the potential adopter rather than individuals (i.e. technology acceptance).

The study is the first attempt to comprehensively investigate how construction technology follows a specific pattern for disseminating technologies by vendors, and refers to the gap in knowledge how classifying vendors based on their dissemination strategies, would potentially shape the adoption process. The major contribution of the study is the creation of the methodological cube for investigating a construction technology adoption process (CTAP). This process goes beyond previous studies focusing on the individual customer's intention to use a specific information technology at a single stage, by developing a systematic framework where:

- the adoption process consists of separate stages;
- each stage comprises unique activities;
- the process steps of the decision makers (customers) are paralleled by clearly identifiable steps taken by vendors;
- the characteristic of the technology (e.g., large crane) and the need of the customer (e.g., start new project) result in discernible pathways within the adoption process;
- the applications of the CTAP cube provide discernible sub-patterns within the process which would be applicable for different technology types;
- the study also pointed out to factors contributing to the adoption decision process, which would be mapped to the stages different phases of the adoption in the future; and
- the study identified the individuals (or more specifically their roles) involved in different phases of the process are identified.

Another contribution resides in the exploration of different patterns of decision makers and how this affects the details of their decision making. The original disparity of the behavior of family businesses in adopting a new construction technology compared with construction contractors was also identified. This was traced to the different interaction networks that arise in the different organizational structures. The new comparison between Australian and American customers and vendors shows the similarities of the adoption process in different regions.

As with any empirical research, there are limitations to how representative the samples collected from the two developed regions (Australia and North America) were compared to the rest of the industry worldwide including developing regions or even just the industry in Australia, Canada and/or USA. Each developing country has notable differences in the use of construction technologies. For example, the interviews show that Latin American customers are less feature oriented than North American customers. The interviews also show that in some regions of African and Middle Eastern countries, customers prefer to purchase second hand technologies of famous brand manufactures rather than purchasing new technologies to obtain reliable equipment without paying high capital costs. Future studies should investigate different regions to find the most important factors in each to help vendors align their dissemination strategies with local customer preferences.

The data covers a wide range of construction technologies, but the total range of construction technologies is wider again and other patterns may be found in larger samples in different regions. Therefore, more investigations are needed to generalize the findings of this study across different countries as well to explore new patterns of decision maker characteristics.

The scope of the study has been limited to the construction industry. Future research could examine if the framework is applicable to transportation and mining, due to the similarity in many of the technologies used. The study covered technological innovation (e.g. tools and heavy equipment); further research could examine the applications of the framework to other types of innovations in construction such as materials and temporary works.

6. Conclusion

The purpose of this paper was to develop a deep understanding of the possible methodologies for digital technology adoption investigating how customers make decisions for adopting the technology and how vendors support them in this decision process. This paper presents how the hypotheses were systematically tested that the industry follows specific decision processes linked to the pre-adoption process for investigation, and the post adoption process for implementation. It showed that the literature about the construction technology adoption process concerning the decision process is scarce. For example, the existing studies in information technologies claim that the adoption decision only involves one stage, occurring after "*persuasion*" [157]. Detailed explanation as to how the decision is being made and what would happen in this single stage has not been covered.

Significant and clear gaps of understanding construction technology adoption at the organizational level were identified, particularly regarding vendor involvement in the process. This led to hypothesizing a conceptual framework delineating the construction technology adoption process, which was the basis for the remainder of the study. In order to validate the framework, main strategies were chosen: technology exhibition visits to immerse the investigator in the customer-vendor market community over a period of four years; semi-structured interviews to collect details of the current practices of the decision-making process; and an AHP survey to evaluate contributing factors. Using these strategies, substantial first-hand data was collected from technology exhibitions and through conducting semi-structured face to face interviews spread across Australia and North America involving both customers and vendors to cross-validate the results.

An important message that this study imparts is that construction technology adoption is largely subject to a systematic sequential process involving two sides, customers and vendors, and their interactions. The proposed CTAP – including its stages and customer-vendor interactions in each stage as major original hypotheses – was confirmed.

The original contributions of the findings of this paper lie in its careful design, collection and analysis of two different samples from both customers and vendors to establish a scientifically sound understanding of the stages of adopting new technology. For example, the testing of the prepared hypotheses led to four key observations: each adoption phase consists of three stages; each stage comprises unique activities and tasks towards technology adoption; the process stages of the decision makers (customers) are paralleled by clearly identifiable stages taken by vendors; and multiple individuals in the organization are commonly consulted.

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Conflicts of Interest: The authors declare no conflict of interest.

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