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Chapter

# Adaptation: A Lens for Viewing Technology Transfer in Construction Site Management

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## Abstract

This book chapter presents the results from a series of studies which explored the use of the technology transfer (TT) subconcept of adaptation to explain the uptake of recent information and communication technologies (ICT) in the construction industry. The specific focus is the management of construction site processes. The studies explored the need for management process enhancement, availability of relevant information and communication technologies, occurrence of such technologies in construction site management (CSM), influencing factors, and challenges to their adoption in construction site management. Results from stages in the phased methodology are used to generate certain hypotheses that are based on analysis of primary and secondary data. Insights from testing the hypotheses and findings from the series of studies are used to model an adaptation-based understanding of the transfer of information and communication technologies in construction site management. While using site management as the specific focus, the study contributes an understanding that is relevant to the construction industry and other project-related environments.

**Keywords:** adaptation, adoption, construction, management, ICT, IT, site management, technology transfer

## 1. Introduction

The focus of this chapter is the use of the concept of adaptation [1], which is a subconcept of technology transfer (TT) [2, 3], to explain the uptake of recent digital and automation technologies, here classified as information and communication technologies (ICT), in the built environment. The chapter looks at management functions, specifically focusing on construction site management (CSM) and its process. The chapter is based on a series of studies within a doctoral research project. The following themes were explored: the construction industry in a continuously changing environment, implications of changes and increasing complexities of construction sites, challenges and strains to site management, human weakness and limitations in managing construction sites, and technology in an evolving construction industry. It was possible to highlight the realities being faced by the building and construction sectors, and the use of ICT to enhance the site management process, in the face of attendant challenges and limitations.

The construction sector is arguably a big role player in every economy, and the CSM process is strategic in the construction process, being the management of physical delivery of the construction product. The term product refers to any type of physical facility, structure, and infrastructure. Despite appreciable research, technology uptake in the construction industry has been regarded as slower than other sectors. While there is increasing uptake of ICT in construction, there is a persistent shortfall in the exploitation of benefits offered in recent outputs of such technologies. This is especially true in developing countries such as South Africa, which was used as context for the research project, where studies such as [4, 5] suggest the need for more ICT uptake. Without an increase in utilisation of ICT, potential benefits for various aspects of construction, including CSM, remain untapped. The situation is undesirable, considering the sector's need for performance in the face of persistent demand for more development. The construction sector is commonly used by governments, as a vehicle for physical and social development, thereby increasing the limitations and pressures experienced in managing projects. The implications for CSM, the need for management process enhancement, and the relevance and potential of recent ICT and its slow uptake in construction formed the research background. For scope, three focus areas were chosen: site materials management (SMM), site health and safety management (H&S), and site information management and communication (IM&C). The research problem was articulated as follows: Exploitation of the adaptability of recent ICT developments to improve the site management process is suboptimal, resulting in lost opportunities that manifest as lapses in information management and communication, H&S, and materials management.

Thus, the broad research aim was to investigate the exploitation of the adaptability of recent ICT developments to improve CSM and to build an understanding of the nature of this exploitation through the lens of adaptation, in order to ultimately generate propositions for addressing the suboptimality.

### 1.1 Initial theoretical studies in the research project

The research project included an extensive literature review and a multistage investigation strategy, set in South Africa, spanning an initial time frame from 2008 to 2013. From 2014 to 2019, more research was carried out, generating papers and articles, extending the literature, and addressing the many sub-objectives of the wider research project. Between 2008 and 2019, the research project resulted in 14 research papers, of which 2 were based on extensions of the research, by supervised students, 4 (4) journal articles, and a doctoral thesis. A historical perspective of publications from the initial studies is presented in **Table 1**.

Except for publications in 2010, all papers in **Table 1** are theoretical. This period saw an extensive theoretical exploration of various areas deemed relevant to the research, using secondary data and limited primary data. Results of [6–8] substantiated the need for an improved CSM and the need to use ICT for that purpose. This was followed by substantiation of CSM needs in relevant aspects such as SMM and IM&C [10, 11]. The need for user-centredness, in terms of usability, acceptability, ICT readiness, and/or skills issues, was substantiated in [9, 12]. In 2010, the relevance of contextual and compatibility issues such as the developing country context, local ICT education, and indigenous technology cultures was addressed, with empirical data in [13, 15]. From the studies in **Table 1**, it was determined that in the face of unparalleled pace of output from the ICT sector, it was reasonable to query the noted slow pace of ICT adoption in construction. In order to explain the situation within the scenario of CSM, various useful subconcepts of innovation [16] and technology transfer were considered, as discussed in section 2.

| Reference | Publication | Year |
|---|---|---|
| [6] | Improving site management process through ICT | 2008 |
| [7] | Achieving ubiquity in the site management process: a theoretical study of the potential for innovative ICT solutions | 2008 |
| [8] | Improving materials management through utilisation of information and communication technology | 2008 |
| [9] | Balancing site information and communication technology systems with available ICT skills | 2009 |
| [10] | Information and communication technology – based application of 'just-in-time' (JIT) to internal logistics on site | 2009 |
| [11] | Enhancing on-site communications by adaptation of multimedia systems: looking into the future of construction | 2009 |
| [12] | Improving people-centeredness in H&S risk management through ICT | 2009 |
| [13] | Cutting-edge technology for construction<br>ICT in a developing country | 2010 |
| [14] | Information and communication Technology education within South African built environment schools | 2010 |
| [15] | Indigenous iron technology evolution: lessons from Uzu culture of Awka in Nigeria | 2010 |

**Table 1.**
*Historical perspective of initial publications from the research project.*

## 2. Summary of theoretical basis for the research

In the research, information was accessed from historical and more contemporary literature. An appreciable effort was made to understand the relevant and key concepts and theories, including theory of reasoned action (TRA) and theory of planned behaviour (TPB) [12, 13]; technology acceptance model (TAM) [14, 15]; unified theory of acceptance and use of technology (UTAUT) [12]; technology-organisation-environment (TOE) framework [16]; MIT90 model of organisational information system innovation [17]; business process adaptation models, referred to as business process automation (BPA) [18, 19]; structural equivalence theory [20]; threshold innovation theory [21]; and the process theory, among others [22]. Considering the research focus, technology (i.e. ICT) and its transfer were determined as key issues. The research inherently centred around the parent concept of technology transfer. Hence, relevant theories and concepts were explored, including technology and technology culture [23, 24]; TT [2, 3, 25]; innovation [11, 26]; diffusion [27, 28]; diffusion of innovations [27, 29, 30]; adoption theory [29, 31]; adoption and user acceptance [29, 31]; the function of knowledge in adoption and innovation diffusion [29]; and adoption model based on the contagion concept, social influence, and social learning [32]. Going through the plethora of relevant concepts and theories, none adequately or fully explained the interaction of people and ICT in the unique area of CSM. Further deliberation led to the concept of adaptation [33, 34], which was employed as the main perspective for understanding the results.

### 2.1 The adaptation concept

The word adaptation appeared as a borrowed term, originating from Latin in the thirteenth century. The term was used in both the tangible and the abstract sense. The modern use of the term began in the sixteenth century [33]. It is derived from

a Latin root *apt* or *apt-us*, which refers to something that is appropriate, or suited for purpose, or the context, which is in turn derived from the root *ap-ere*, meaning to fasten, affix, clip onto, or attach. It can be defined as the process or the product of these actions [34]. Adaptation is also described as making fit, and it will involve more than simply imposing something into a different setting [35]. The definitions allude to adaptation being purpose-driven [34]. Adaptation as a generic concept has expressions in disciplines such as psychology, biology, anthropology, sociology, and geography [33]. By extension it has been used to explain certain patterns of TT. While many authors allude to the concept in defining and describing TT, there are others such as Brooks in [25] '...explicitly theorizing adaptation as a sub-concept of...' TT, being a process of moving technology, '...from more basic scientific knowledge into technology or adaptation of an existing technology to a new use'. Furthermore, in [36] TT is described as having two possible routes: by means of imitation and through an analogy, which means that '...the technology must be adapted before it can be adopted...someone must see an analogy between the characteristics of the original invention or innovation and the requirements of the new situation'. The outline of the TT process in [25] shows that the receiver of technology will either repair and maintain; modify and adapt; or design and produce new equipment or products, based on the technology. Adaptation is also described as a fundamental concept in technology transfer in [37]. Here it highlights the significant movement of technology between different sets of users and the movement of technology for the purpose of application towards addressing another problem apart from that for which it is originally designed. Furthermore, it is arguable that the process of diffusion in some cases may produce a profoundly different result from the original technology. There could be a case of slight modifications which may be a 'fine-tuning' requirement. The technique of applying the technology could also be addressed differently in varying degrees.

With TT as the parent concept, and the subconcept of adaptation as the lens for the research, key assumptions held in the research include the following: While diffusion and innovation exist in their own rights, they also manifest in technology and its transfer; technology and its transfer embody innovation in thought, process, and activity; diffusion is the spread component of the transfer process; technology and TT, innovation, diffusion, and innovation diffusion all share a close relationship; technology could be described as innovation; TT involves innovative practices which generate more innovations and practices through which innovations spread or diffuse into society; technology is more than the artefact; and technology is made up of different bodies of knowledge and their related techniques, contraptions, contrivances, machines, and material and immaterial things, among others. As a subconcept of technology transfer, which is viewed here as a systemic concept, adaptation borrows from the concepts of innovation and diffusion. Furthermore, due to the breadth of applicability of the adaptation concept, it manifests some features and attributes of other concepts and theories that are relevant to TT. In this case, adaptation is framed by technology innovation, technology diffusion, and diffusion of innovations. Moreover, innovation and diffusion exist in other knowledge areas apart from technology. As such they are not only defined within TT alone. However, they frame adaptation within TT, as presented in **Figure 1**.

In the research, analogies were drawn from most of the intellectual traditions of the adaptation concept. The psychology dimension relates to issues of perception of CSM level participants in construction. Such perceptions result from interaction with ICT, with other humans through ICT, and with other humans who use ICT. There is also the issue of perception of CSM process needs and utility in the ICT. The biology and anthropology traditions relate to the need to survive, remain competitive, and be technologically advanced for CSM people and construction industry organisations. It also speaks to the mutual adaptation

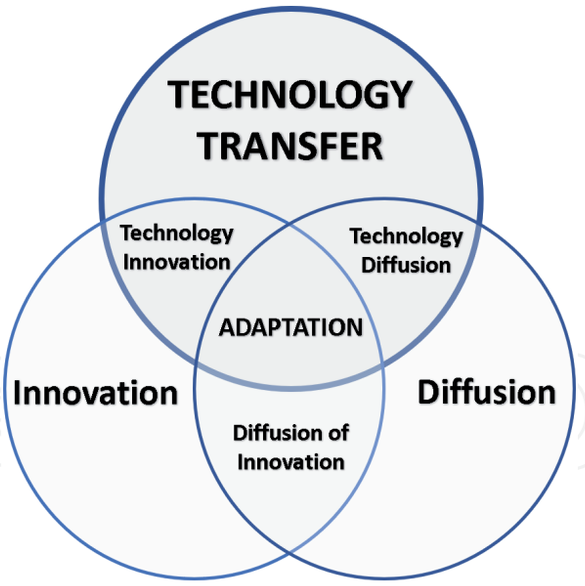


**Figure 1.**
*Framing of the adaptation subconcept of technology transfer [38].*

that occurs in the engagement with technology, especially ICT. The sociology and geography traditions relate to the influencing environments, which would impact on the nature of adaptation of ICT in CSM. Following the analogies, the adaptation concept identifies 'structural or functional similarities in otherwise dissimilar situation of things' [36]. This description refers to the identification of opportunities in recent ICT, for weaknesses/inefficiencies/lapses in the dissimilar situation of CSM process. Hence, attributes of the research concept include that in recent ICT, there are utility, structural, and functional characteristics, and features, which are referred to as ICT potential utility. The exploitation of ICT potential utility for CSM through adaptation involves specific steps. Recent ICT is assessed to identify potential utility for possible process enhancement in CSM. The relevant application of such potential utility could be via direct usage, through a degree of modification, or integration of features into a hybrid system. It could be used as a component of other innovative products, and in areas of relevant application. CSM is investigated to compare the available ICT and its transfer. The areas of need in the CSM process, which could be improved by exploitation of ICT potential utility, are determined.

Following the preceding discussion, constructs generated from the study include time frame, which refers to the time frame to complete the adaptation process; unit of adaptation, which is about the key agency in the adaptation; type, which refers to the extent, aspect, and depth of adaptation; pathway, which refers to the natural route of adaptation based on the nature of required/initiated adaptation; and process, which is focused on the source, pattern, end point, and location of adaptation. These were reduced to measurable attributes or variables and examined through a bespoke research methodology.

## 3. Research design for the chapter

The overall methodological dimensions for the wider research project could be described as a mixed method [39] and multistage research design [40], which utilised quantitative and qualitative data. A fundamentally descriptive purpose was adopted, which started with an exploratory approach and ended with an evaluation.

Essentially, the subject was explored, to describe it in full; then further exploration led to confirmations, evaluations, and, ultimately, a final description. Multiple sources were used, according to the stages in the research design and in compliance with the research concepts and the constructs. Based on the research as determined through preliminary studies, a complex set of units were studied: construction sites, practitioners, manufacturers, and products. The main unit of analysis in each case was ICT in CSM, though the outcomes were different for each stage.

Investigations in the research project started with an exploratory single project, multisite case study. This was followed by a global survey of relevant ICT, a national survey of practitioners in South Africa, a case study of multiple project sites, and a final ICT product analysis. Purposive samples of construction sites, ICT-based products, and construction project management practitioners were chosen. The tools used include observation and interview schedules, content analysis schedules, and questionnaires. MS Excel was used in the initial data analysis. Other analytical tools were employed subsequently.

## 4. Summary of results and findings and evaluation of hypotheses

In the research project, the first stage was a case study of a highly critical single project with multiple sites, presenting rich baseline information for the research. The highly limited occurrence of ICT, appreciable occurrence of weaknesses in CSM, and apparent lack of awareness of some opportunities in recent in ICT were indicated [38]. The global ICT survey results showed a significant indication of a continuously growing list of ICT products, which are relevant to CSM. There is variety for adequate choice to be made for relevant needs. The products exist locally and internationally. They are accessible through the Internet, physical representation by various manufacturers, and a large population of local vendors. This stage was used in [41]. Product types which are well adapted for CSM, such as mobile hand-held devices and geographic surveillances, have appreciable variety. Such significant adaptation and variety highlight the possible influence of usability and user acceptance, which is a function of the extent of adaptation of the product. Such products would continue to experience further adaptations, towards user demands. It would also follow that the more use an ICT product line experiences, the more transformation the product would experience towards user requirements. In comparison, the national practitioner survey indicated a very low degree of innovativeness in the exploitation of ICT potential utility among practitioners. Results showed that while digital surveying equipment was highly utilised, laser ranger and measurer which are directly related to surveying were not comparatively utilised by site managers on site. High usage of mobile hand-held devices occurred with very low usage of wireless technologies and services. This stage was used as empirical basis for [42]. There was appreciable contrast between knowledge and awareness and utilisation of various ICT types. Apparently, knowledge and awareness of ICT did not necessarily translate into usage within CSM. Similarly, self-assessment of skills for such ICT and some depth of utilisation did not translate to utility of the same ICT in SM by practitioners.

The practitioner survey was also used to explore the experience of barriers to ICT uptake from participants. Network service problem was the highest indication. Results of comparative analysis with findings from the literature review showed adequate correlation in terms of the severity of barriers. Essentially, major challenges seem to emanate from technology and management support and the knowledge adequacy of the practitioners. This stage was used as empirical basis for the study presented in [43]. The fourth stage was a case study of four

purposively selected construction sites. Content analyses, walk-through observations, and informal interviews and evaluations were used for collecting data. The occurrence of lapses in CSM and occurrence of relevant ICT, and its utilisation, were the areas of exploration. This stage was used in [44]. Findings indicated appreciable occurrence of management shortcomings or lapses on sites, largely due to human limitations, general management strains and inefficiencies, and the human factor. The observed lapses demonstrate strains on site management, which constitute process need areas [38, 44], that can be addressed by adapting potential utility in available ICT. The issue of knowledge was also highlighted. The last stage was the ICT product study. While determining the existence of ICT with such adaptability was central to the research, the main counterpart was assessing the utility of this adaptability for CSM. Therefore, a purposive sample of ICT products was analysed, through physical observation and content analysis of manufacturer's technical documents and online reviews. This stage was used to further substantiate the existence of potential utility in recent ICT that are relevant to CSM.

### 4.1 Findings and discussion

Findings from the multistage research project were articulated into publications and additional research and publication of more research papers and articles. The output includes publications based on core empirical data from the research, except for [38], which is the unpublished thesis, and [45–47], which are co-authored with research students. In the latter case, the work was based on the focus, theoretical support, and supervisory guideline, from this research project. See **Table 2**.

Between 2012 and 2013, the first set of core empirical data was used, looking at user awareness and user perception of challenges and effectiveness of ICT [45, 48, 49]. Results highlighted limited knowledge and technology support, but a perceived process improvement and better project experience from adoption of ICT. Extant

| Reference | Research output | year |
|---|---|---|
| [48] | ICT in site management process in South Africa | 2012 |
| [38] | Main research report (unpublished Thesis) | 2012–2013 |
| [49] | Investigating barriers to ICT adoption in Site management: a pilot study in South Africa | 2013 |
| [45] | Participants' perceptions on investment in ICT and project outcomes in South Africa | 2013 |
| [42] | Exploring the knowledge function in the adoption of ICT in site management in South Africa | 2014 |
| [46] | Use of ICT-based systems in site security management: a South African study | 2014 |
| [41] | Market availability of information and communication technologies and their adoption in site management in South Africa | 2017 |
| [47] | ICT in the training of South African bricklaying operatives: a pilot in the Greater Johannesburg area | 2017 |
| [43] | Exploring challenges to ICT utilisation in construction site management | 2018 |
| [44] | Process need areas and technology adoption in construction site management | 2019 |

**Table 2.**
*Historical perspective of empirical output from the research project.*

literature in [50] also indicated the quality of the technology as a strong determinant of ICT use. A causal relationship between ICT use and project performance was also established. In [42], the function of knowledge [29] was explored further and [46] was focused on site security management as an aspect of CSM. From the results, it was determined that knowledge-related factors could be indirectly influencing other challenges, such as lack of management support and ICT requirement analysis and input in contracts. There were indications of possible patterns according to age group and experience. In [42] it was concluded that '...the extent of awareness, skills and working knowledge has not approached the adequacy level to increase adoption of ICT in site management appreciably'. The need for more awareness is highlighted in the recent literature such as [51]. Skills and training, which are knowledge-based, were also highlighted in [52]. However, one significant finding was that knowledge did not translate to adoption and use in every case. In 2017, the global ICT survey data was compared to data on awareness and utilisation of relevant ICT in CSM [41]. In addition, a unique area, training of bricklayers, was used to collect and test current data in terms of market availability of ICT and its occurrence [47]. Results show proof of local availability and access to recent ICT but a relatively poor level of awareness among practitioners and training providers for building trades. The impact of knowledge-related factors was further highlighted. In 2018, the studies on barriers to ICT utilisation were taken forward in [43]. Existing studies, various groupings, and different terms of framing were explored internationally and locally. Results generated the current framework for naming, categorising, and understanding challenges to ICT in CSM, which is supported by literature such as [53, 54]. The possible compounding effects of knowledge, technology, and management support factors were highlighted. In extant literature such as [53], the need for management support and increased availability of technology was highlighted. In [43] emergent patterns of identification of challenges according to age and work were indicated. End user response was identified as highly critical for success, highlighting user acceptance, usability, ergonomics, ease of use, and 'adaptability of the ICT to different related uses' [43], among others. Such issues are supported in literature such as [54, 55]. In 2019, the construct of process need areas [38, 44] derived from the research was also taken forward. Recent literatures and relevant concepts and theories were examined and applied. A pluralistic approach of using five theories/concepts was employed to explain the results, highlighting the need for a more comprehensive framework. It was again noted that acquisition of technology and utility of the technology's adaptability are different issues with varying impacts. While technology was embraced, the exploitation of inherent potential utility was not necessarily occurring in the final use. Results highlighted the need for process improvements in CSM, the limitations and inefficiencies in CSM, and the benefits of ICT for CSM. Findings are supported in extant literature such as [56, 57].

### 4.2 Summary of the evaluation of the research hypotheses

Following the discussion of findings from the research, five hypotheses were generated, to test the emergent ideas. The hypothesis evaluation process was tailored to the research methodology. Thus, a corresponding multistage approach was used. The process involved breaking down each hypothesis into subhypotheses, and they were evaluated individually, using data from various stages in the research methodology. Results were then outlined in summary as evidence for evaluating the main hypothesis, using the rules of evidence for evaluating the hypotheses. Essentially the null hypothesis in each case is rejected if the summary of evidence significantly

supports the claim in the corresponding hypothesis. Otherwise, the null hypothesis is not rejected. To analyse the data sets for evaluation of the hypotheses, the following were used: descriptive statistics, inferential statistics, content analysis, and narratives. The procedures included Z test of proportions [58, 59] and chi-square test of goodness of fit [58]. Initially MS Excel was used as the main analytical tool. Subsequently, other tools such as Stata, ATLAS.ti, NVivo, WordStat, and Qualtrics were added. Frequency and contingency tables, means and proportions, and chi-square tests were used for most of the analysis. In addition, the Z test of proportions was used for the ICT and practitioner surveys.

The first hypothesis, HP1, states that there is limited knowledge of recent ICT-based goods and services that are commercially available, due to lack of awareness and usage in CSM. HP1 was broken down into two subhypotheses, HP1-a (assessing the commercial availability of recent ICT which are relevant to the SMP) and HP1-b (addressing the issue of limited knowledge of recent ICT among practitioners in the SMP). Inferential statistics applied to test availability of recent ICT products indicated that majority of products (above 75%) are available locally and internationally, at 5% level of significance with a minimal 2% risk of error. Secondly the identified ICT types have variety in terms of 85 brands and 439 subbrands, making up a total of 1635 products. Thirdly out of a total possible availability value of 2, all product types had values of 1.8 or above. Similarly, significant occurrence of limited awareness of recent ICT was established from the stage 3 practitioner survey data. Less than 50% of respondents indicated awareness for up to 8 out of the 17 original ICT types considered. Less than 50% awareness values were indicated for the majority of the products (18 out of the 34 types). Furthermore, stage 1 case study indicated that only 3 out of the 35 ICT types under consideration were observed for the 3 sites visited. Moreover, in stage 4 case studies, less than 50% of ICT types under consideration were observed for the 4 sites visited. The evidence supported the commercial availability and range of choice in the majority of recent ICT, for CSM; significantly limited awareness and usage of recent ICT among CSM practitioners; and lack of on-site usage of recent ICT in CSM. Therefore, HP1 is supported.

The second hypothesis (HP2) was stated as follows: The adaptation of recent ICT for the SMP is suboptimal due in part to limited knowledge and management and technology support. HP2 was evaluated through two lenses, namely, HP2-a (suboptimal adaptation) and HP2-b (stated barriers to ICT in the SMP). The summary of evidence showed that the evaluation of HP1 established the limited knowledge of recent ICT for CSM. In terms of adaptation, descriptive analysis of practitioner survey data showed the highest indication of ICT awareness as less than 50% of the highest possible value. Other attributes/variables of ICT adaptation such as use, skills, and on-site use were all under 23% of their highest possible values. Aggregated values indicated a grand mean of 75.35 out of a possible 290. Thus, suboptimal adaptation of recent ICT in CSM was evidenced. Inferential statistics indicated a lack of adaptation of ICT in CSM at a statistical significance of more than 65% or 0.65 of the highest possible sample mean. The case studies evaluated in HP1 and their emergent narratives confirm the low occurrence of ICT in CSM. The narratives also show a strong indication of limited management support. In addition, results from exploring the challenges to ICT in CSM support the hypothesis claim of the relatively higher severity of limitations in technology and management support. Moreover, narratives from stage 4 case studies show strong indications of limited knowledge of potential utility in recent ICT. As such within the research scope, adaptation of recent ICT for CSM was found to be suboptimal, due in part to limited knowledge and management and technology support. Therefore, HP2 is supported.

The third hypothesis (HP3) was stated as follows: Increased adaptation of recent ICT could enable ubiquity and real-time operation of the site information management and communication system. HP3 was evaluated through HP3-a (availability of recent ICT and their relevance to information management and communication in the CSM) and HP3-b (occurrence of lapses in the SMP due to poor information management and communication, which could be addressed through the utility of recent ICT). For the summary of evidence, evaluation of HP1 and HP2 established the availability of recent and relevant ICT products in HP1. The global ICT survey, final product study, and mapping of utility for CSM performed in the research were used to confirm that the majority of the identified ICT are relevant to IM&C. Evaluation of HP2 established the lack of occurrence and suboptimal utilisation of ICT in case study sites and also linked the indicators to suboptimal adaptation of ICT in CSM. Furthermore, the case studies highlighted lapses in site IM&C. This is supported by inferential statistics from the practitioner survey data. The evidence supports the notion of appreciable availability of recent ICT which are relevant to IM&C; the occurrence of lapses in site IM&C; and the occurrence of suboptimal adaptation of relevant ICT to site IM&C. Therefore, HP3 is supported.

The fourth hypothesis (HP4) was stated as follows: Increased adaptation of recent ICT for site H&S management could improve real-time monitoring and reporting. The evaluation of HP4 was broken into three areas, namely, availability of recent ICT and their relevance to site H&S; lapses in site H&S; and suboptimal utilisation of recent ICT in CSM. In terms of evidence, HP1 established the availability of recent and relevant ICT products in HP1. HP3 established the primary relevance of up to 20 ICT items to site H&S and the relevance of recent ICT to site IM&C, which form the basis for HP4. HP2 established the lack of occurrence and utilisation of ICT in case study sites. The same evaluation also linked the two indicators to suboptimal adaptation of ICT in the SMP. Furthermore, results of the case studies provide evidence of lapses in site H&S and lack of occurrence of relevant ICT and their utilisation. HP1, HP2, and HP3 strongly support the claim of suboptimal adaptation of relevant ICT in site H&S. The evidence supports the existence of appreciable availability of recent ICT which are relevant to site H&S management; occurrence of lapses in site H&S; and suboptimal adaptation of relevant ICT to site H&S. Therefore, HP4 is supported.

The fifth hypothesis (HP5) was stated as follows: Increased adaptation of recent ICT for on-site materials logistics could result in efficient and dynamic logistics management. HP5 was also broken into three areas, namely, availability of recent ICT and their relevance to site materials logistics; lapses in site materials logistics; and suboptimal utilisation of recent and relevant ICT for site materials management. In terms of evidence, HP1 and HP3 were used to establish the availability of recent ICT products and their relevance to site IM&C, which forms the basis for HP5. HP3 and further mapping of ICT potential utility established that an appreciable proportion (22/34) of recent ICT is relevant to site materials logistics. HP2 established the lack of occurrence and utilisation of ICT on case study sites and linked the indicators to suboptimal adaptation of ICT in CSM. The case studies also present an evidence of lapses in site materials logistics and lack of occurrence of relevant ICT and their limited utilisation SMM. This is supported by HP1 and HP2, on the claim of suboptimal adaptation of relevant ICT in SMM. As such HP5 is supported.

Following the derivation of findings, synthesis with literature, and evaluation of generated hypotheses, it was possible to build appreciable understanding of various attributes/features of the adaptation concept of ICT transfer to CSM. The understanding is presented in the next section.

## 5. An understanding of the adaptation concept of technology transfer of ICT in construction site management

Part of the aim of this research was to build an adaptation-based understanding of the transfer of ICT to the CSM. This section presents an exploration of the attributes, constructs, and concepts, the development of their frameworks, and the articulation of a basic flow model and a detailed conceptual model to explain the nature of the adaptation concept of TT, as it applies to ICT in CSM, and construction in general. In addition to process need areas and ICT potential utility, other derived constructs include time frame of adaptation, unit of adaptation, type of adaptation, pathways, and process of adaptation.

### 5.1 Concepts/constructs generated from the research

The construct of time frame is based on the time factor in diffusion of innovation theory and the innovation decision process. For any outcome and process of adaptation, there is a time frame. The time frame could be immediate in the case where the technology's usefulness is identified simultaneously with awareness of it. Then, the identified potential utility is immediately exploited. There could however be a considerable time lapse of short term or long term. Short term would occur within one construction project event. Long term would occur during multiple project events and probably at an organisational scope or level.

Unit of adaptation as a construct refers to the key agent of the adaptation. Basically, it asks the question: Who is implementing the innovation? The answer could be the individual end user, the work group within a project, the project team/group, or the project organisation. There is also a possible third case where it is initiated by the individual, work group, or project team but adopted and powered by the organisation, all within one process of adaptation. A further possible scenario is the case of adaptation by a project stakeholder other than the contractor, such as client, design team, or major supplier. However, they are viewed as being within the project team or organisation. The unit could also be an external party, while the outcome is meant for construction.

The type of adaptation is comparable to the concept of hard and soft technologies, which has found popularity in the climate change remediation discourse. It refers to the mode taken in adapting technology. Hard adaptation mode is the type that requires modification or fine tuning of technology prior to its usage in the intended environment. The example would refer to physical hardware modification and software re-engineering. Soft adaptation mode refers to a degree of minimal alteration, but it relates more to idea components in innovation diffusion. It would therefore not involve any re-engineering of hardware or software. The innovation is on ideas, not involving physical things. It could also be on an idea on which a product is based. Such adaptations may eventually result in hard adaptation.

The pathway construct is related to the type construct, in that it traces the routes for hard and soft types of adaptation. For pathways, hard adaptation involves hardware adaptation and software adaptation. Soft adaptation could be by ready adaptation, usage adaptation, or context adaptation. Ready adaptation (adoption and use of a well-adapted innovation) is based on the view that adaptation is both a process and an outcome. Therefore, activating the process and acquiring an outcome of the process both fall within the description of adaptation. An example would be the need for remote communication with someone on site and the task-technology fit [60] of the mobile phone which is essentially obvious. Usage adaptation means adapting to a different use from the originally intended use. In one of the case studies in the project, a service provider used a laboratory acidity tester

to check the identified groundwater in order to determine if it was portable water leakage or otherwise, using the acidity level. Context adaptation involves adapting from a different intended/primary usage environment to another. The preceding example is also relevant in this case. This category includes adaptation from one sphere, or discipline of origin, to another. The use of laser and infrared scanner in construction and the use of telepresence would be good examples.

Process construct refers to the process of ICT adaptation. It could be completely internal, where it is initiated and completed within a project site/event (internal process). It could also be internally initiated but completed externally in another sector, due to capacity requirements (internal-to-external). In this case the external sphere may be beyond the CSM situation, beyond the immediate project organisation, and at an industry or sectoral level.

To further understand the application of the adaptation concept in this context, the time frame matrix of ICT adaptation is presented in **Table 3**. The time frame construct is used as a categorisation frame, to understand the dynamics of their systemic relationships. While the table is not exhaustive of all possibilities, it gives a clearer sense of what occurs in ICT transfer in construction, from the adaptation perspective, according to time frame.

From **Table 3**, hard adaptation refers to physical or software modification of product, while soft adaptation refers to adaptation without physical adjustment to the product specifications. Hard adaptation could be minor or major. For pathways, there are hardware adaptation and software adaptation, specific to ICT. For process, there is also the case of externally initiated and completed adaptation by an external party, but within the CSM (external process). An example would be where a relatively temporal participant who is external to a project identifies a need and adapts technology to address the need, due to the very limited project exposure. Adaptation could also be initiated by an external party but assumed and completed by site management within CSM (external-to-internal). An example would be where a known need in CSM is addressed through adaptation of technology, by an interested party, who is external to the project, or industry.

Long-term adaptation processes would be the domain of the industry and organisation system levels. This is the realm of strategic alignment and

| **Adaptation construct** | **Immediate** | **Short term** | **Long term** |
|---|---|---|---|
| Unit | Individual | Organisation | Industry level |
| | Work group | Project level | Organisation |
| Type | Hard adaptation (minor) | Hard adaptation (major) | Hard adaptation (major) |
| | Soft adaptation | Soft adaptation | Soft adaptation |
| Pathway | Ready adaptation | Ready adaptation | Ready adaptation |
| | Context adaptation | Context adaptation | Hardware adaptation |
| | Usage adaptation | Usage adaptation | Software adaptation |
| | | Software adaptation | |
| Process | Internal process | Internal process | Internal process |
| | External process | Internal-to-external | Internal-to-external |
| | | External-to-internal | External-to-internal |

**Table 3.**
*Time frame matrix of ICT adaptation in CSM [38].*

organisational management decisions and implementation. The organisational level transcends the short term and long term and enables effective translation of strategy into implementation. Between short term and immediate occurrence, the division could have grey areas because there are more individuals influencing the dynamics of adaptation in these divisions. However, hard adaptation would not occur in the immediate as it requires some degree of preconditioning of the ICT before use. It is argued that soft adaptation could occur within the short term and long term, depending on how sensitive management is to their needs and relevant opportunities. Similarly, usage adaptation could occur in the short term, but context adaptation pathway and internal-to-external adaptation process would typically fall into short term and long term. Ready adaptation could also be long term, in the case of management taking considerable time to make decisions. Furthermore, protracted implementation processes would inevitably result in long-term adaptation. Moreover, it is possible that some forms of adaptation could outlive a project and continue in other projects, at an organisational level. A basic conceptual model of the dynamics of adaptation of ICT in CSM is shown in **Figure 2**, using the cluster of constructs and attributes in their subenvironments and the flow of the adaption process within this context.

Time is used as one major environment of the adaptation process, to emphasise the feature of duration. However, there are other environmental factors such as compatibility requirements [61], which influence the adaptation of technology generally. Arguably, compatibility requirements would include monetary compatibility, which refers to the financial demands of transferring the technology; materials compatibility, which refers to the receiver being able to provide compatible material resources for the functioning and maintenance of the technology; production level compatibility, which refers to the technology being able to function productively and/or being replicated in the receiving environment; infrastructure compatibility, which refers to the availability and reliability of the enabling infrastructural environment; social and political compatibility, which refers to factors such as culture, national, and political interests and skills; and ecological compatibility, which refers to the environmental impact of the technology. It also refers to the technology being transferable in an environment [61].

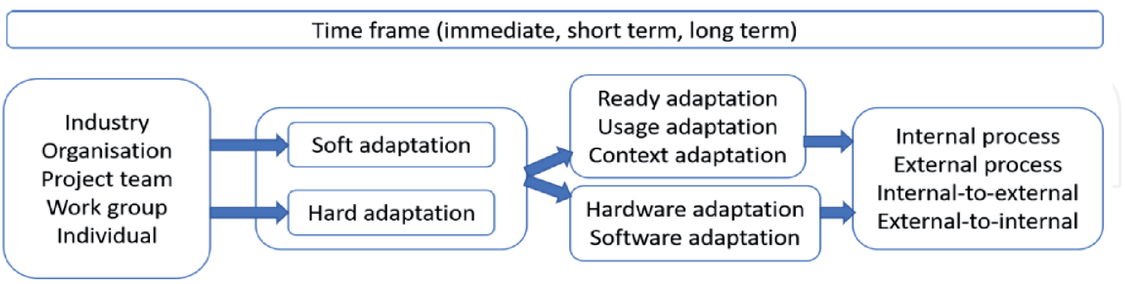


**Figure 2.**
*Basic conceptual model of the dynamics of adaptation of ICT in CSM [38].*

From the findings and discussions thus far, and developments in **Table 3** and **Figure 2**, a detailed conceptual model of the nature of ICT adaptation in CSM, and in the construction projects, is proposed in **Figure 3**.

The attributes are organised in their subsystemic relationships, and their systemic relationships, using the unit, time, process, type, and pathway constructs as bases. The unit construct is primary, followed by time. The type of adaptation and its process and pathway then emerge. The project-related situation, which is the unit, could be an individual, work group, project team, firm or organisation, or the industry.

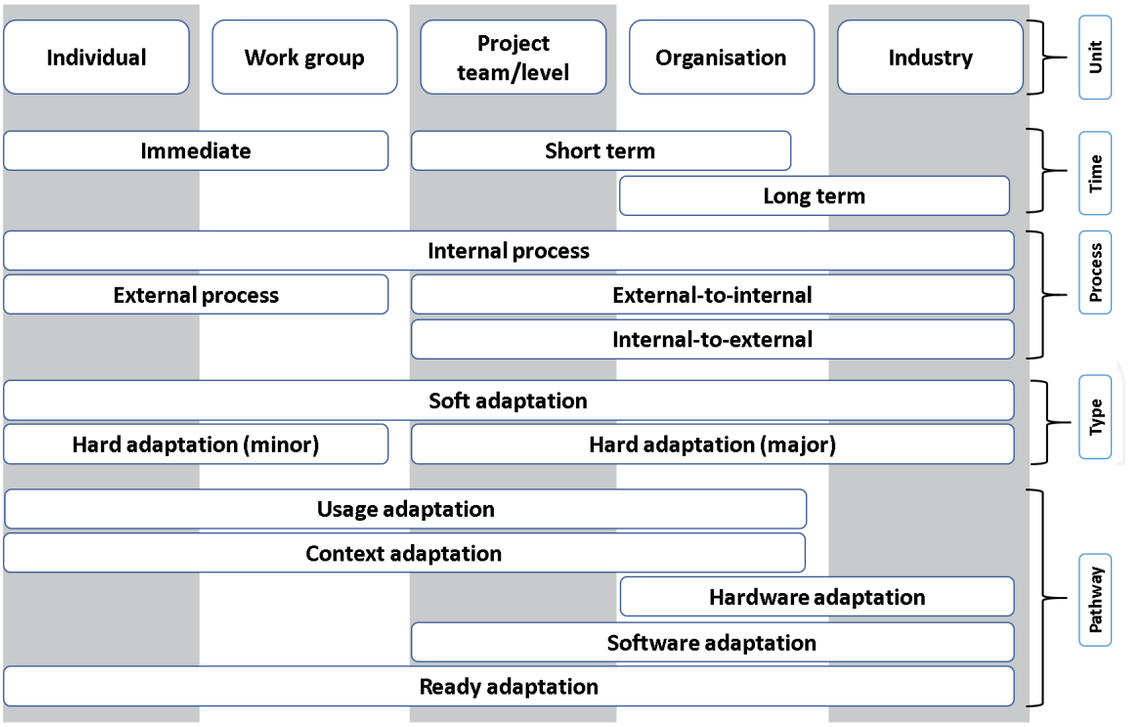


**Figure 3.**
*Model of adaptation dynamics of technology transfer in CSM [38].*

## 6. Conclusions

This chapter presented a research on the uptake of ICT to enhance construction site management process, using the South African context, through the lens of the adaptation subconcept of TT. Essentially, the exploitation of the adaptability of recent ICT to improve CSM was investigated. Through the series of studies leading to the chapter, the common thread has been defined by a collection of concepts/constructs, which embody the essence of the research: information and communication technology; technology; technology transfer; diffusion; the site management process; and adaptation. A deeper understanding of innovation [62], technology acceptance and adoption [63], moderating effects on adoption [64], and the nexus between user-centeredness and technology acceptance [65], was derived. The central discussion is the exploitation of adaptability in recent ICT, as opposed to the adaptability itself, which is established in extant literature. This approach addresses a management problem rather than an application problem.

### 6.1 Overview of the research

The research is predicated on the problem of suboptimal adaptation of potential utility in recent ICT to improve the CSM. Three aspects of CSM were focused, namely, H&S, SMM, and IM&C. Though various research methods have inherent weaknesses, a robust methodology with adequate rigour was developed to address such weaknesses. The research was conducted through a mixed method, and multistage research design, which generated results and hypothetical statements. The hypotheses alleged suboptimality in the exploitations of ICT potential utility to improve CSM in the focus areas, limited knowledge of available relevant ICT, and the existence of some key challenges to uptake of ICT in CSM. The literature review on technology, ICT, and the construction industry pointed to the sheer capacity of modern technology, especially ICT. It also highlighted the applicability, scalability, and pervasive nature of ICT. These attributes substantiate the adaptability

of recent ICT, which could be usefully exploited to achieve far-reaching advantages in construction, especially CSM. Following the deductions from literature review and conceptual basis for the methodology, the analysis of data showed a strong evidence of the existence of gaps identified in the literature. It also presented more telling indications in the local context. Suboptimal exploitation of the adaptability of recent ICT for CSM was highlighted. Issues of limited awareness, limited working knowledge, and limited management and technology support were highlighted. The gravity of these specific issues and their synergistic impact on ICT adoption in CSM was strongly supported by the evaluation of the hypotheses. The overarching deduction with regard to the research problem is that the hypotheses as stated are supported. Within the limits of the research project, the results strongly substantiate the claim that the exploitation of the adaptability in recent ICT to improve the CSM is suboptimal. This flies in the face of the proliferation and availability of such technologies and the performance of other industries in that regard.

### 6.2 General conclusion to the research

Findings from the literature review are that ICT adoption in CSM is inadequate and inexpedient, falling short of potential benefits for construction. The literature review for this research revealed the need of humans for technology to enhance their natural processes and take full advantage of their natural environment. This need has evolved and extended to every aspect of human life including construction and CSM. Literature also revealed that construction has developed largely through technological innovations. Particularly the industry in recent history has grown by exploiting the adaptability of technology originating from other sectors such as ICT. Through innovation, rather than reinvention, many technologies have been successfully adapted to construction in areas such as CSM. Literature revealed the capacity and pervasiveness of ICT in modern life and its relevance to the enhancement of CSM. Nevertheless, adaptation of ICT to construction and CSM depends appreciably on factors including awareness and working knowledge and technology and management support. CSM contends with challenges of limited human capacity, overstretching of management, and blind spots in overseeing the site constitutions and activities. This leads to lapses in various areas of CSM such as IM&C, H&S, and SMM. Thus, the SMP has many potential beneficiary areas for adaptation of recent ICT. However, literature from the study has also shown that the construction industry in general falls behind other industries in adapting potential utility of recent ICT to improve CSM. While not entirely resulting from the lack of adequate ICT, lapses observed in CSM case studies demonstrate weaknesses in site management, which cannot be effectively addressed through increase in personnel as observed. In practice, not all designated personnel are on site at the same time, due to unsustainability of such measures. Furthermore, there is currently no known substitute to ICT in addressing requirements of ubiquity and real-time capacity.

Field research results pointed to underutilisation of innovations located in recent technology. The main causative factors include inadequate knowledge of potential utility of recent ICT and a lack of effective approaches to technology integration and management support. Results highlight the fact that all possible units of adaptation agency can initiate and drive the required innovation. Beyond the primary usage of products, there is more utility offered in their designs and specifications. It is therefore important that usage of ICT goes beyond what is immediately discernible as practical usage. Exploiting potential utility in recent ICT requires innovative thinking and approach in their use. The need identified here applies to the individual, group, project team, organisation, and industry. Thus, while the demand for construction products and better delivery persists, putting construction under more

pressure, the ICT sector continues to produce relevant products, services, and ideas which can be usefully exploited by construction. Useful exploitation of such output would enhance construction performance in many areas.

Through a customised approach, the research established foundational understanding of the adaptation of ICT in CSM. Contributions from the research include the time frame matrix of adaptation of ICT in CSM, the basic flow model of adaptation of ICT in CSM, and the detailed conceptual model of adaptation of ICT in CSM. Thus, the research contributes to the following bodies of knowledge: technology transfer, innovation, ICT in construction, user experience of ICT in construction, adaptation of ICT in construction, and construction project management. The proposed model is arguably relevant to the exploitation of the adaptability of ICT in other project-based systems and environments, beyond CSM, construction project management, and the construction industry.

The work presented in this chapter is the conclusion to a research project which was first proposed in 2007 and essentially started in 2008, generated a doctoral report in 2013 and additional publications up to December 2019. Through 19 publications, the attributes and dynamics of the adaptation concept for TT of ICT in the CSM have been derived, framed, and modelled. The outcomes at this stage are still not exhaustive of all possible scenarios. Future studies should therefore focus on the uptake of ICT/IT in other aspects of construction, user experience (UX) issues, other levels of construction project management, and comparison of the adaptation concept with other relevant concepts, and the use of contributions from the current study, to work on ICT based solutions for various needs in construction. Such studies should also aim to develop a deliberate/formalised approach to the transfer of ICT in construction, using the natural patterns discovered in the research, emphasizing user centeredness and user experience.

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