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USING MOBILE COMPUTING FOR CONSTRUCTION SITE INFORMATION MANAGEMENT

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ABSTRACT

Purpose – The objective of this paper is to develop a model for the use of Mobile Computing in the management of on-site construction information and communication.

Design/methodology/approach – The research strategy contains three steps: a pilot study for the first stage, a survey that investigated the information needs of particular users and the nature of on-site information, and finally the development of a model and the validation and evaluation by operational scenarios.

Findings – The developed model explores how mobile computing can be used on construction sites to manage on-site information. This model, firstly, identifies the key factors of mobile computer, wireless network, mobile application, construction personnel, construction information, and construction site; secondly it describes the relationships and interactions among these factors. Based on the model, the selection process for mobile computing strategy includes the clarification of information management process, the creations of overview for mobile computing solution, the identification of mobile computing strategy, and the selection of appropriate mobile computing technology.

Originality/value – The developed model explores the general concepts and the internal relationships at the two areas of mobile computing and construction site information management. The application of the model can help users to select mobile computing strategies for managing on-site construction information based on the characteristics of their projects.

Keywords: Construction industry, information management, Mobile communication systems

Paper Type: Research paper

INTRODUCTION

Construction information management has greatly benefited from the advances in Information and Communication Technology (ICT) in increasing the speed of

information flow, enhancing the efficiency and effectiveness of information communication, and reducing the cost of information transfer. Current ICT support has been extended to construction site offices. However, construction projects typically take place in the field where construction personnel have difficulty in gaining access to conventional information systems for their information requirements. The advances in affordable mobile devices, increases in wireless network transfer speeds and improvements in mobile application performance, give mobile computing technology a powerful potential to enhance on-site construction information management. However, before employing this new technology, it is necessary to identify the features of mobile computing, construction personnel, construction information and construction site, and explore the interactions that are likely to affect the implementation of mobile computing in on-site information management.

This paper presents a research project which considers how mobile computing technology can be best employed in managing on-site construction information. On-site information management and the application of mobile computing in construction are described. Following a description of the research carried out, the model is introduced with detailed explanations on its nature and practical application. An illustrative example of how the model can be used in the selection of mobile computing technologies is presented. The paper concludes with a brief discussion on the potential benefits and limitations of the proposed model.

CONSTRUCTION SITE INFORMATION

Construction sites are information intensive environments where actual construction processes and activities are carried out. Various construction personnel in the field need large amounts of information ranging from project design drawings to personal diaries to support their ongoing works and to make decisions about the process of construction. In order to explore and develop effective methods for on-site information management, the starting point should be the identification and categorization of on-site construction information.

Several researchers have investigated on-site construction information from various perspectives. In de la Garza and Howitt's research (1998), on-site construction information was grouped into ten major categories from a generic construction project perspective. These ten categories include requests for information, materials management, equipment management, cost management, schedule and means and methods, jobsite record keeping, submittals, safety, QC/QA, and future trends. Each category was further divided into more detailed subcategories. For example, the group of materials management contains the following five subcategories: access to material management, material location, material order status, request materials to site and place material orders.

From a site record perspective, Scott and Assadi (1999) have summarized three types of site records, which consist of a range of information relating to finance, quality and progress. Especially, the progress records typically kept by contractors and supervisors aim to identify the works carried out during the project life-cycle and consist of site diaries, weekly progress reports, day-work sheets and joint records, photographs, as-built programmes/schedules, and minutes of progress meetings.

In an earlier research, Tenah (1986) explored the information needs from a user's perspective and stated that the information needs of each members of the project team are inextricably linked to their management responsibilities. Construction personnel are divided into five levels, each of which has different management responsibilities and information needs. For example, at the functional management level, the foreman's information needs consist of drawings, specifications, contract documents, local union activities, safety regulations labour agreements, quality control, progress and field performance reports.

Due to the complex nature of the construction process and the dynamic nature of construction sites, the management of on-site information usually inefficient and leads to low productivity. The most effective way for construction personnel to manage information on sites is to retrieve or capture information at the point where they are and at the time when they need it. However, this ideal situation has been difficult or impossible with traditional information management methods, which are normally the organization and maintenance of paper-based documents. Bowden et al (2004) indicated that the main type of information that onsite construction personnel receive and transmit is paper-based, which poses a major constraint for site information communication and exchange. Ineffective on-site information management can result in personnel overlooking important issues that require quick response and often cause on-site decisions to be deferred (Singhvi and Terk, 2003).

The development of Information Technology (IT) gives the construction industry a powerful potential to increase the efficiency and effectiveness of information exchange, but current IT support has only extended to construction site offices and they are still gaps between site offices and actual work sites. The emergence of Mobile Computing (MC) has the potential to enlarge the boundary of information systems from site offices to actual work sites and ensure real time data flow to and from the construction sites.

MOBILE COMPUTING AND CONSTRUCTION INFORMATION MANAGEMENT

The concept of Mobile Computing (MC) has been considered to consist of three major components: computers, networks and mobile applications (Rebolj and Menzel, 2004). Computers which can be used indoors and outdoors by users include tablet PCs, all kinds of pocket computers, palmtops and wearable computers, but exclude conventional notebooks. Networks which can support the connection and communication of mobile computers with sufficient bandwidth include all types of wireless networks such as Wireless Wide Area Networks (WWAN), Wireless Local Area Networks (WLAN), Wireless Personal Area Networks (WPAN), and satellite networks. Mobile applications with the attributes of context-sensitivity and personalization can support mobile users' work processes and enable them to work together collaboratively and cooperatively in a mobile computing environment.

With the consideration of the characteristics of construction sites and construction processes, one major question should be carefully considered: what are the necessary requirements for applying mobile computing in construction information management?

After interviews and discussions with construction managers, Kimoto et al (2005) identified nine necessary requirements for mobile computing, which are mobility of hardware, durability of hardware, compatibility of hardware and operating system (OS), compatibility of data between the mobile devices and PC, expressivity of display, stability of system, operability of user interface, processing speed, and continuous computing environment.

With advances in Information Technology and the decreasing price of computer hardware, current commercially available mobile devices, wireless networks and mobile applications can fulfil the above necessary requirements. The current status of Mobile IT have been discussed in the report of the COMIT project, which briefly describes the mobile devices, networks and computer applications currently in use in the construction industry (COMIT, 2003). In the three components of mobile computing concept, mobile application is the key factor that responds to specific characteristics of mobile devices and wireless networks and support users' work process by enhancing the efficiency of information communication. Based on commercially available products and related research, mobile applications can be grouped into the following three categories:

- *Mobile CAD Applications*. Construction personnel using mobile devices equipped with mobile CAD applications can view, mark-up, create, edit and collaborate on 2D/3D AutoCAD compatible designs and digital blueprints anywhere and at anytime when they are on construction work sites. Users of mobile CAD applications may contact anyone who needs the support of drawings and designs in the construction field, such as engineers, project managers, designers and drafters. Most mobile CAD applications are compatible with popular mobile devices running Windows CE, Windows Mobile or Palm Operating Systems. In order to communicate drawing files with desktop PCs, mobile CAD applications can connect and exchange data with PCs by using ActiveSync for Windows OS or HotSync for Palm OS. Example applications include PocketCAD, PowerCAD and ZipCAD.
- *Data Capture Applications*. There are three types of data capture applications used in the field, which include data capture, bar code scanning and wireless sensor network. SHERPA (Ward et al., 2003) is one of the mobile data capture systems, which enables users to utilize workforce driven mobile computers to collect real time piling work data in the field through a Wireless Local Area Network (WLAN). A bar-code-enabled PDA application, named the Mobile Construction Supply Chain Management system (M-ConSCM), has been developed to improve the effectiveness and convenience of information flow in a construction supply chain environment through integrating a PDA and bar code scanner together (Tserng and Dzeng, 2005). Wireless Sensor Network that consists of various devices capable of a cooperative sensing task is a new innovative technology similar to the concept of Ubiquitous Computing. A mass concrete curing management system (CMS) has been developed to investigate the possibility of applying Wireless Sensor Network to on-site data collection processes (Lee and Kang, 2006). This system can allow the collection, transfer, and delivery of the recorded curing temperature data automatically in real time in a Wireless Sensor Network environment.
- *Project Management Applications*. Applications in the project administration area provide users with the capabilities of project and programme management such as

construction activity review, activity monitoring and updating, progress management, risk management, Microsoft Project file view and update, and material and equipment management, through their on-hand mobile computers. Available commercial applications include Primavera Mobile Management, CYtools, and OnSite FDM.

RESEARCH METHODOLOGY

According to current developments in mobile computing technology and the status of on-site construction information management, the potential opportunities of mobile computing are best deployed in the area of on-site information communication. In this research, a construction site is considered to comprise two components: the construction "work site" and the "site office". The work site includes all areas outside the site office, and the site office is the headquarters for project (site) personnel. Construction personnel in this research refer to those managerial people whose work places are mainly based on construction sites. The aim of this research is to identify opportunities for applying mobile computing in construction site information management and to develop a model that explores how mobile computing technology can be used in construction site environments to retrieve and transfer on-site information. This proposed model will identify all major factors and their associations, which affect the design, implementation, and maintenance of mobile computing in on-site information communication. In order to validate and evaluate this model, various operational scenarios were developed to demonstrate how mobile computing can be used to retrieve and transfer information on particular construction site, and how mobile computing can enhance the effectiveness of the construction process for particular users.

In order to achieve the objectives of this research, an appropriately designed methodology is necessary. The research strategy contains three steps: a pilot study for the first stage, a survey that investigated the information needs of particular users and the nature of on-site information, and finally the development of a model and the validation and evaluation by operational scenarios.

After the reviews and evaluations of previous research and published literature, a conceptual model was developed from the perspective of information management (Chen and Camara, 2005a). This conceptual model integrates mobile computing technology with each level of information management, and explains the relationships between each of them.

After setting up the conceptual model, a case study was conducted in February 2005 (Chen and Camara, 2005b). It involved visits to three construction sites with varying project types and interviews with various construction personnel. Findings from this case study identified the varieties of roles on construction sites, the main information they need to support their construction activities, and current IT support.

A web-based survey was conducted to investigate the information needs of particular users, the nature of on-site information, and the mechanisms of retrieving and transferring information on construction sites (Chen and Kamara, 2006). The survey was conducted via the Internet, first as a pilot survey and then a final survey. The

results of the pilot survey were excluded from the final analysis since it was corrected and improved for format and content problems in the structured questionnaires.

Findings from literature review, case study and the survey were used as the evidence to set up the final model. The analysis and generalisation of features of commercial available mobile computing products provided the identification of sub-factor for the primary factors of 'mobile computer', 'wireless network', and 'mobile application'. The visit of construction sites and the interviews with construction personnel presented the general environment and circumstance of 'construction site' that is one primary independent factor in the model. The survey coupled with the case study identified the sub-factors, such as 'user's role', 'user's mobility', 'information type', 'information format', 'file size', and 'information flow', for the two primary factors of 'user' and 'construction information'. The concept model as the results of literature review indicated the link between the user and the mobile computer, which is the issue of Human Computer Interaction (HCI) presented in the final model. The information requirements of different construction personnel provided the evidence of what types of construction information mobile computing have to deal with and the concern of how mobile computing can meet user's information needs. The nature of on-site information investigated in the survey raised the consideration of how mobile computers coupled with mobile applications can input and output construction information and whether wireless network has the capability to transfer them at satisfied speed. The mechanism of construction site information management indicated the information sources from which users retrieve information and the information destinations to which users transfer information by applying mobile computing technologies. The directions of information flow require mobile computers and mobile applications to have relative connection method and data transfer methods. In general, findings from literature review, case study and the survey provided the identification of primary factors and sub-factors, and the exploration of interrelationships between these factors.

MODEL OF MOBILE COMPUTING IN ON-SITE CONSTRUCTION INFORMATION MANAGEMENT

The third stage of this research was to establish the model that explores how mobile computing can be used on construction sites to manage on-site information. This model, firstly, identifies the key factors of mobile computing, construction personnel, and construction information and construction site; secondly it describes the relationships and interactions among these factors. The intention is to use the model to provide guidance in the effective deployment and selection of Mobile Computing for on-site information management.

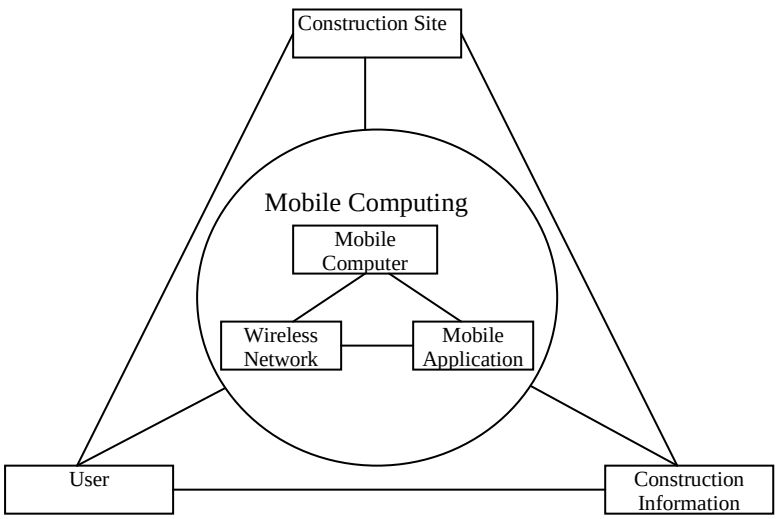

Figure 1: The Framework of Using Mobile Computing in On-site Information Management

The top-level model, shown in Figure 1, consists of six primary factors: three independent factors and three dependent factors. The three dependent factors, which are ‘mobile computer’, ‘wireless network’ and ‘mobile application’, are the fundamental components of the concept of mobile computing. The three independent factors, - ‘users’, ‘construction information’ and ‘construction site’, - are the elements that determine the use of mobile computing in a particular context. The independent factors indicate the specific construction environment at which mobile computing will be implemented to manage information, and determine the design of mobile computing systems. Therefore, the three components of mobile computing are the dependent factors that the consideration of implementation should depend on the various construction circumstances decided by independent factors.

In order to explore the interrelationships between independent and dependent factors in great depth, the primary factors have been further divided into sub-factors and the top-level model is therefore decomposed into various sub-models, each of which represents the detailed relationship between two primary factors. Figure 2 shows the sub-model that contains sub-factors of primary factors including ‘construction information’, ‘mobile computer’, ‘mobile application’, and ‘wireless network’. As an example, the independent factor ‘construction information’ is divided into seven sub-factors: information type, information format, file size, information flow, information processing, information source, and information destination. As the dependent factor, ‘mobile computer’ contains the following sub-factors: operating system, processor speed, storage capacity, data input, data output, physical feature, battery duration, and connection method.

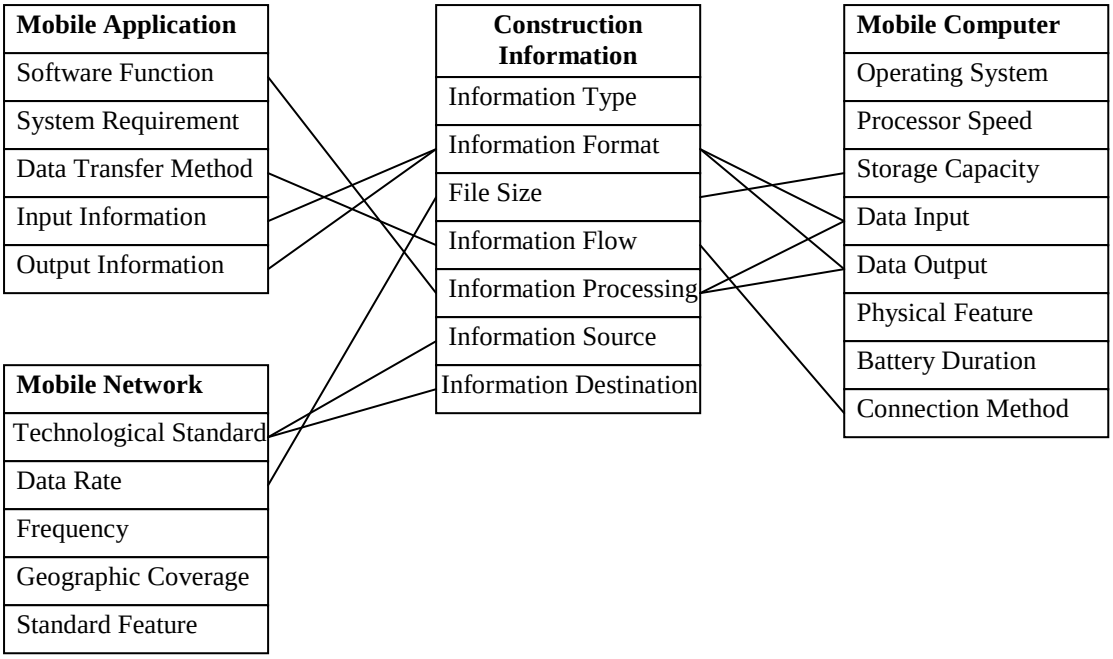

Figure 2: Interrelationships between Construction Information and Mobile Computing

Construction information referring to the on-site information that users retrieve to or transfer from construction sites have its own characteristics compared with other information types. The use of mobile computing systems in managing construction information should address these specific features. The sub-model in Figure 2 also shows the interrelationships between construction information and mobile computing and is discussed as follows:

- **Construction Information and Mobile Computer.** The link between construction information and mobile computer concentrates on how mobile computer presents and provides specific construction information to users. One of the features of construction information is that it is represented in various formats including graphic, imagine, text, form and verbal. The format of construction information has a major impact on the output method of the mobile computer; similarly the output mechanism of the mobile computer can restrict the output format of construction information. For example, when a user needs the mobile computer to display construction drawings, the screen size of mobile computer limits the expressional scope of drawings. The requirement of displaying large size drawings can be fulfilled from the hardware aspect by choosing a mobile computer with larger size screen. In addition, the input methods of mobile computer including keyboard, touch-screen input and voice recognition input, determine what types of information format can be inputted and how efficiently this can be done. The storage capability of the mobile device should be able to store the necessary information files; on the other hand, the file size for mobile application software should be smaller and only keep necessary software functions in order to fit in the limited storage capability.
- **Construction Information and Mobile application.** Information format also has influence on the software perspective of data input or output. For example, the requirement of displaying large size drawings can be fulfilled from the software aspect through the design of drawing viewer software with the functions of zoom

out, zoom in, scrolling, mobbing and layout. Functions of mobile application should fulfil the requirements of information processing performed by user on construction work sites. Users' information processing activities include viewing drawings, editing files, making notes, and taking pictures or videos, which should be carefully concerned when selecting appropriate mobile application software. The information flow of construction information refers to whether information is retrieved from other construction employees to construction work sites or is transferred from construction work site to other project information system or employee. Data transfer methods of mobile application should meet the requirements of information flow with the consideration of efficiency, effectiveness and convenience.

- **Construction Information and Wireless Network.** The selection of wireless networks for construction information transfer should concern the file size of information that need to transfer and whether the network's data rate or bandwidth have the ability to transfer information reliably and without delay. Other factors that affect the selection of technological standard for wireless network are the information retrieval source and the information transfer destination. If information source is the computer system in site office, Wireless Local Area Network that covers the whole construction site is enough for user to retrieve information by using mobile computer. If information source is construction personnel, user can simply use Smart Phone or Pocket PC Phone to make a phone call via the cell phone network or IP phone network.

The above discussion explored the interrelationships between construction information and mobile computing. The whole model investigates all links between independent factors and dependent factors. Primary factors are divided into sub-factors and the top-level model is also broken down into different sub-models that represent specific relationships.

APPLICATION OF MODEL FOR SELECTING MOBILE COMPUTING STRATEGY

One of the applications for the developed model is to select mobile computing strategy for managing on-site construction information. The overall selection process includes four major stages: the clarification of information management process, the creations of overview for mobile computing solution, the identification of mobile computing strategy, and the selection of appropriate mobile computing technology.

The Clarification of Information Management Process

The aim of the first stage is to clarify and map out the selected information management process that could derive benefits from the implementation of mobile computing. In this stage, the relevant construction process will be analysed, the characteristics of construction information will be identified, and the information management process will be developed and recorded. The output of this stage is the process maps that clarifies and reflects the procedure of information management for select construction process. There are many useful techniques and tools that can assist designer to analyse and map out the information management process. Figure 3 shows the process and techniques that can be used to map out processes.

1. Define Process

- Define process boundaries
- Determine process aims and roles
- Identify its relationship to involved users

2. Analyse "As Is" Process

- Background reading
- Interviewing
- Questionnaire
- Observation
- Document Sampling

3. High Level Analysis

- Rich Picture
- "Use Case" Diagram
- "Collaboration" Diagram

4. Process Map

- UML
- Scheduling Methods
- Data Flow Diagram
- IDEF0
- Petri Nets

Figure 3: The Procedure of Mapping out Information Management Process

The Creations of Overview for Mobile Computing Solution

In the second stage, areas that can be improved by proposing mobile computing on the process map will be highlight and the desired position on each highlighted area will be identify with regard to the use of mobile computing.

Areas that can be improved by implementing mobile computing technologies such as PDAS, Tablet PCs, Bar-coding, Wireless Sensors, GPRS/GSM/3G, Wireless LAN, and Mobile Application Software, can be identified by taking account of the following guides:

- Information management activities where information is retrieved to construction work sites by paper.
- Information management activities where information is processed on paper such as view, amend, edit, check, update, collect, and record.
- Information management activities where information is transferred from construction work sites by paper.
- Information management activities that could be fully automated if electronic data is available.
- Information management activities involving the communication with other personnel using traditional methods (e.g. by telephone, fax, or post).

- Information management activities involving the information exchange from person to person, person to information system, person to document storage place, work site to site office, site office to headquarter, which can be replaced by mobile computing.

After highlighting the areas where the implementation of mobile computing can improve the efficiency and effectiveness of information management, the modified process map can show how the original process can be re-engineered by applying mobile computing. The output of this stage is the modified process map that reflects the changes where mobile computing is introduced to assist users to manage construction information.

The Identification of Mobile Computing Strategy

The third stage aims to assist user to select appropriate mobile computing strategy that can re-engineer the information management process from current situation to desired position. Figure 4 is the pre-defined "square" that identifies the current situation, the desired position and the different mobile computing strategy and indicates the different ways that information management process can be re-engineered from current situation to desired position.

In this figure, the current situations of on-site information management are paper-based information communication, non-automatic information management activities, and traditional information communication methods including post, fax, and telephone. In order to improve the efficiency of on-site information management, the desired objectives contain the implementation of digital information communication, automatic information management activities, and the use of mobile computing for on-site information communication. For the achievement of desired objectives, the three mobile computing strategies represent different extents of implementing mobile computing to manage information on sites. The first strategy uses commercial available mobile application software and mobile computers, and synchronises data between mobile computers and site-office-based computers via wired connections (USB or Ethernet) or short range wireless connections (Bluetooth or IrDA). Compared with the first one, the second strategy provides the coverage of wireless networks (WLAN or WWAN) on construction work sites. The third strategy indicates the design of the whole mobile computing system with respect to the particular construction situation and users' requirements. This strategy includes the design of specific software, the selection of appropriate mobile computers, and the establishment of wireless networks.

Additionally, in response to the features of different information management process and various construction situations, the general "square" can be modified in terms of add or reduce the mobile computing strategies based on user's own circumstance. As the result of selecting the specific strategy, the desired information management process will be revised to reflect the selected mobile computing strategy.

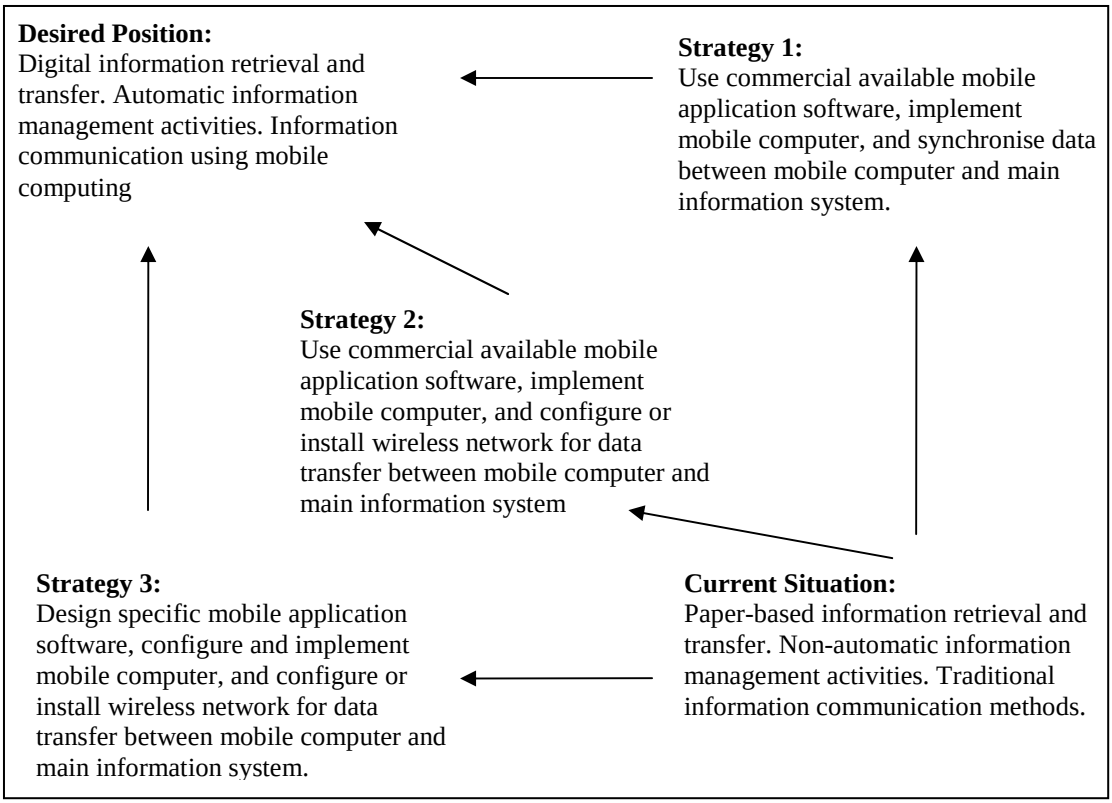

Figure 4: The Mobile Computing Strategy Matrices

The Selection of Appropriate Mobile Computing Technology

The final stage focuses on the selection of appropriate mobile computing technologies for the specific mobile computing strategy selected in the third stage. For each mobile computing strategy identified in last stage, the appropriate mobile computing technologies including mobile computer, wireless network and mobile application software, will be selected based on the developed model of mobile computing in on-site construction information management. Restrictions and interrelationships that may facilitate or inhibit the implementation of mobile computing in managing on-site construction information will be also identified. This can enable the organisation to develop specific plans to implement the selected mobile computing technology that relates to their mobile computing strategy.

Figure 5 is the example of how mobile computing technologies can be selected according to the developed model. In order to remain the coherence with the discussed sub-model in previous section, this figure only concerns one independent factor ‘construction information’ and represents how construction information can affect the selection of mobile computing technologies. Moreover, the use of the model

should concern all three independent factors and their influence on the technology selection.

FURTHER WORK

In the final stage of the research, the developed model will be evaluated and validated in order to compare to realisations of the reality. The validity of this model will be demonstrated through an illustrative example. Case study is going to be used as the research method to evaluate this model in a real construction situation through the use of scenarios of specific construction operations. After the selection of construction project and the investigation of project background, site visits and interviews of on-site construction personnel, whose work places are based on the site office and construction work sites, will be conducted. The interview will focus on the investigation of respondents' roles, their responsibility, construction processes they are involved in, information they retrieve and transfer on sites, and information sources and destinations. Based on the real construction circumstance, the illustrative scenarios will be set up to demonstrate the processes of selecting mobile computing strategy that were identified in the developed model.

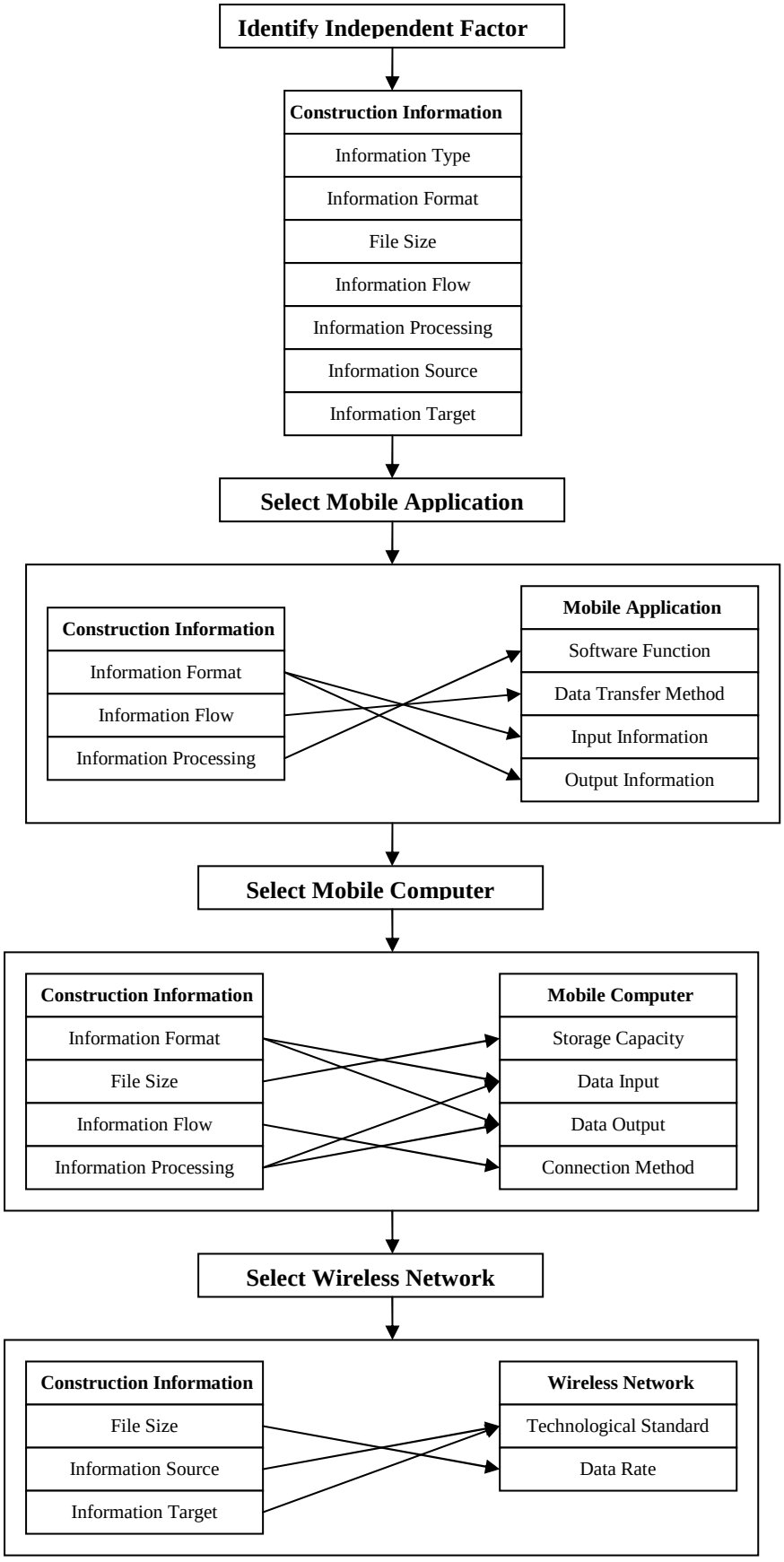

Figure 5: The process of selecting mobile computing technologies

CONCLUSIONS

The aim of this paper was to explore how mobile computing can be used on construction sites to manage on-site information. From the review of previous research, on-site information has been grouped from different perspectives with the discussion of the current status and problems of construction site information management. Mobile computing, consisting of mobile devices, wireless networks and mobile applications, should have the necessary functions for it to be used in construction. These functions include mobility and durability of hardware, compatibility of hardware and operating system (OS), and continuous computing environment. Currently available mobile applications includes mobile CAD, data capture and project management software. The research reported in this paper, involved three main stages: a pilot study, a survey, and finally the development and evaluation of a model for the development of mobile computing for construction site information management. The survey has identified the information needs of particular users and the nature of on-site information and provided supports to the development of the model. The concept model has identified the key factors that determine the use of mobile computing in particular circumstance and explore the interactions and restrictions between these factors through the development of sub-models. The conclusion of this research will provide valuable guidance in the use of mobile computing on construction sites, from a user perspective. But further work is required to validate and evaluate it in a real construction situation, for example through the use of scenarios of specific construction operations.

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