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# GIS-BASED RESTORATION SYSTEM FOR HISTORIC TIMBER BUILDINGS USING RFID TECHNOLOGY

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**Abstract**. Using geographic information system (GIS) and other established technologies, this paper develops an information management system that integrates graphic and non-graphic data to enhance the effectiveness of historic building restoration work in Taiwan. Radio frequency identification (RFID) is used to permit real-time tracking of assembly components and thus enhance restoration management efficiency. Restoration data stored in the memory of RFID tags can be changed and updated according to the needs of a specific restoration phase. The use of RFID handheld readers both improves data collection efficiency and system mobility. In the developed system, timber structure restoration data and drawings in the GIS can be accessed online immediately for use in the restoration process and to help advise strategic design, construction, and management decisions. Data of each timber element, including restoration sequence, restoration contractors, supervisors, evaluated strength capacity etc can be retrieved remotely through a handheld PDA reader-writer used onsite. Data of component construction sequence during disassembly or re-assembly, critical to project success, can be transmitted in a synchronized manner to the developed host system to achieve a level of accuracy and reliability significantly greater than that typically achieved using traditional reconstruction management approaches.

**Keywords:** historic building restoration, radio frequency identification, geographic information system, historical timber structure, arcGIS; decision-making.

## 1. Introduction

Field data acquisition is a research topic receiving the increasing attention and importance. Radio frequency identification (RFID) is a novel technology employed to make objects adequately "intelligent" to disseminate information, i.e. through radio frequency. Recently, RFID technology has been applied widely in consumer product tracking and management (Song *et al.* 2006) and is also being used in the construction industry (Jaselskis, El-Misalami 2003; Jaselskis *et al.* 1995; Yagi *et al.* 2005). Construction projects begin with plans, which include a budget, schedule, and designed approaches, that help facilitate effective management. Applying RFID technology has been shown to increase productivity and efficiency, reduce labour hours and cost, and provide more reliable data for estimation. The system is also able to work under adverse/difficult environmental conditions.

When a problem occurs with a component during facility management, the history of that component must be accessed to diagnose and resolve the problem effectively. For a crack occurring on a pre-cast component, for example, data of the material, casting and curing processes during manufacturing phase, transportation and installation conditions during construction phases, and any special conditions faced during its service life must be diagnosed to assess and resolve the problem fully (Akinci *et al.* 2002). Currently, such data are maintained primarily in discrete logs and memos and typically stored electronically in databases distributed across several companies. Collating all relevant historical data to achieve a correct diagnosis and resolution is, therefore, usually a daunting task. Furthermore, a significant amount of time and resources can be expended on discussing and debating potential actions to resolve problems. RFID technology represents a potential solution to this dilemma. RFID tags, attached to individual items, are able to store critical data in onboard memory. RFID technology is used either to read a unique identification number or to read/write data on item tags.

Timber elements are sensitive to microclimatic conditions, and detecting accurately the deterioration status of such elements is critical (Chen *et al.* 2003; Kandemir-Yucel *et al.* 2007). Facilitating an easier access to preservation and restoration data for historic timber buildings is critical due to the value of such buildings as part of society's shared historical heritage. Therefore, proper storage of reliable data and effective access to such can prevent inappropriate repair work and enhance the longevity of these buildings. As many different types of connectors and components are involved in traditional Chinese timber construction, key features and component sequence/linkage data should be stored and made available to restoration decision makers. RFID provides a technical


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solution with regard to the data tracking needs of such an approach.

A successful Geographic Information System (GIS) depends largely on using map projections correctly, with one person's skills in managing and converting projections frequently dictating the overall value of a particular database. GIS software packages provide the GIS analyst with many projections from which he or she must choose one deemed most suitable to a particular need. Map projection selection is a complex process involving an evaluation of map projection alternatives based on a set of characteristics that describe these projections and types of analyses to be performed. Knowledge of map projection selection has been discussed extensively by many authors (Nyerges, Jankowski 1989). GIS is widely applied in map selection scenarios due to its user-friendly interface (Cheng, Yuang 2001; Oswald 2004; Khalid 2006; Stevens *et al.* 2007). One of the most widespread GIS solutions is ArcGIS, which contains more than 60 map projections and allows users to choose the one most suited to a particular project need.

A light and handy IT solution system is preferred for onsite use. Therefore, bulky data and drawings should be avoided in order to keep memory demand and unit size to a minimum. In this study, an in-situ agent system is proposed for historic building restoration in Taiwan. The developed system consists of an RFID system, a PDA connected to the Internet, and a GIS-based building restoration agent system installed on a host computer. RFID tag data are altered, augmented, or updated by restoration contractors during restoration as needed. Restoration contractors can access applicable data including graphic and non-graphic data onsite to enhance the efficiency of restoration work and critical data can be sent to tags by radio frequency and to the host computer via the Internet. Users can access restoration data from the GIS-based system in the host computer with handheld PDAs. Thereby, the developed system facilitates quick query responses and data access between the management office and construction site.

### 1.1. Research purposes and objectives

The primary purpose of this paper was to develop an RFID- and GIS-based system for historic timber building restoration to facilitate decision-making and management. Objectives required to achieve the primary purpose included: (1) to apply an RFID system integrated with a PDA to improve in-situ data collection and storage (read/write) efficiency; (2) to identify essential data associated with historic timber building restoration, during design, construction, and management phases; (3) to develop the in-situ handheld PDA and host systems for management; and (4) to transfer data synchronously and display applicable data during building restoration phases to improve construction efficiency, accuracy, and reliability.

### 1.2. Scope definition

Study scope was defined as follows:

(1) A traditional Taiwan timber structure designated as an historic building.
(2) A timber-frame structure of the "DeiDou" structural sub-type (Fig. 1).
(3) Use of offsite disassembly during restoration.
(4) The disassembly phase comprises 3 sequential sub-phases: component disassembly, component repair, and re-assembly into the structure.
(5) While this study does not discuss tagging methodology, a simple method is to tie RFID tags on components during the construction. However, to restore maintenance records without damage to building components, a preferred strategy is to attach RFID tags to main frames hidden in component joints.

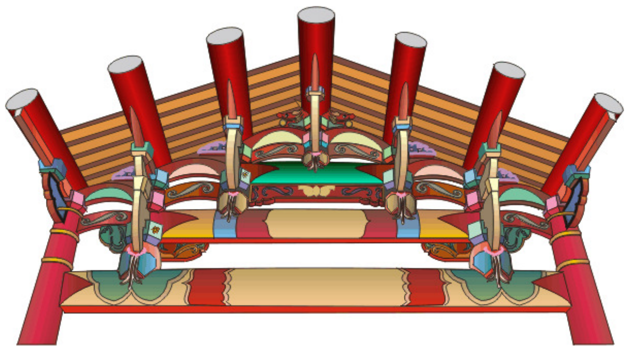

**Fig. 1.** An illustration of an historic building of the "Dei-Dou" timber frame type

## 2. System knowledge

### 2.1. Outline of proposed system

Major software/hardware employed in the proposed system include:

1. CF-interfaced RFID reader-writer (13.56 MHz);
2. Personal digital assistants (PDAs);
3. Microsoft Visual Basic/Embedded Visual Basic;
4. Microsoft Project;
5. MS Access/Pocket Access; and
6. ArcGIS 9.

### 2.2. The RFID system

RFID is an automatic identification technology widely used to identify, track, and detect various objects. The technology used is similar to that in bar code labelling, which uses radio waves rather than light waves to read tags (Cheng, Chen 2002). An RFID system comprises tags and a reader-writer that includes an antenna and scanner. The RFID tag, an electronic label attached to objects used to store data, contains a small integrated circuit chip and antenna encapsulated in a protective shell. The RFID reader-writer antenna and scanner reads/sends data to and from RFID tags through radio frequency. RFID tags can be either active or passive. Active tags, incorporating an internal battery, have a superior read/write range but are bulky and expensive, and service life is limited by power supply capacity. Passive tags are cheaper, smaller/lighter and are activated by radio frequency without the aid of a power source. However, the communication range over which data can be received or sent by passive tags is significantly smaller.

Tags may be designed as "read only" (RO), "read/write" (R/W), or "write once/read many" (WORM). Users read data in tags onsite using a reader-writer, which shares data with the host computer. RFID technology allows users to capture, store, and communicate ID information as well as detailed data on tags. RFID is a proven technology ready to be deployed to capture data efficiently, and it make items intelligent enough to provide both basic identification information as well as relevant critical data.

### 2.3. ArcGIS engine

A successful Geographic Information System (GIS) relies on the proper selection of map projections and the skill of the primary user(s) in managing and converting projections. Map projection selection is a complex process involving evaluating map projection alternatives based on a set of characteristics that describe these projections and the analyses to be performed. A GIS analyst must decide which properties are most important and choose a projection tailored to those needs. GIS software packages such as ArcGIS (which includes more than 60 map projections) allow the GIS analysts to choose from a wide range of alternatives the projection most suited to the specific requirements of a particular project.

## 3. Architecture of historic timber building restoration system

This architecture is developed according to restoration process management and decision-making needs (Fig. 2). Two principal items of hardware, i.e. the RFID system (including tags and reader-writers) and a PDA, are typically used in such project work. The RFID system is used to collect data immediately by radio frequency, store and retrieve relevant tag data, and help in managing the restoration process. The PDA is employed to enhance the applicability of on-site work. In developing a GIS-based system, the first task is to identify data attributes. In this study, data, categorized into graphic (Fig. 3) and non-graphic (Table 1) types, fully describe all historic building timber components. Besides improving automation and efficiency, the developed system greatly increases collected data accuracy and reliability. The uses of the historic timber building restoration system include:

1. *Query and storage of relevant data*

Users can submit queries to access drawings or data. Storage is also provided for data maintenance and extension. Therefore, the database can provide sufficient information to planners, designers, and building contractors involved in historic timber building restoration work.

2. *Restoration management*

By employing RFID technology, users are able to retrieve data immediately. By integrating the data into restoration sequences, schedule etc. restoration project work can be better managed/monitored both in-situ and by offsite managers – greatly improving restoration work efficiency.

3. *Real-time monitoring*

In-situ restoration contractors utilize PDAs outfitted with RFID reader-writers to send/receive data. Data is transmitted to a host computer over a wireless network and may be monitored by supervisors and senior engineers to control the process in real time to prevent mistakes and schedule delays.

4. *Design restoration plan*

Due to the particular importance of taking a prudent approach to historic building restoration, adequate and reliable data must be fully available to restoration project planners. In the event that one or more restorations have been done in the past, records of such can help planners to make improvements and modifications or to determine the most suitable/applicable strategies.

5. *Decision-making and evaluation work*

Regularly scheduled diagnoses are critical for preserving and properly maintaining timber structures. Diagnosis results should be stored for ready reference, so that evaluators may determine which components to repair or continue monitoring and set priority levels. As mentioned previously, data storage is very important in order to facilitate decision-making and evaluation. Diagnosis greatly affects strategies in the maintenance phase and can affect the overall service life of a timber structure.

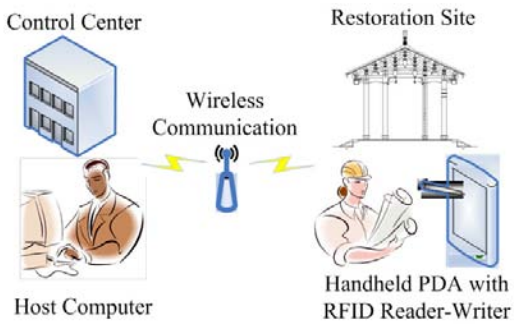


**Fig. 2.** Data transmission used in the historic timber building restoration process

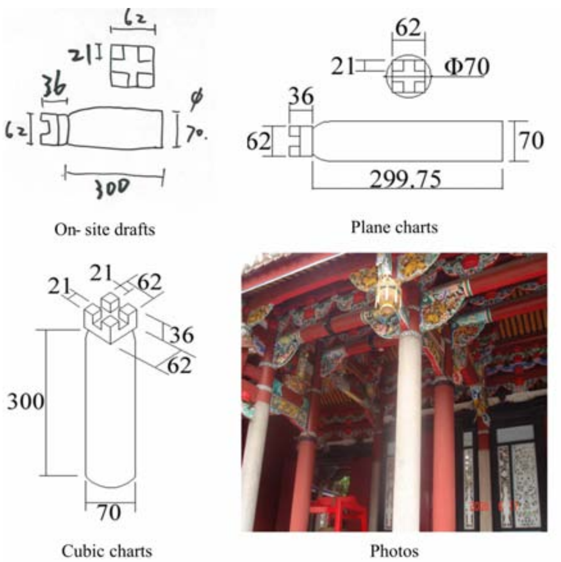


**Fig. 3.** Drawings of timber components in GIS

**Table 1.** GIS timber component data

| Data type | Content |
|---|---|
| Basic Data | 1. Component type<br>2. Location (description)<br>3. Material type(s)<br>4. Condition (description)<br>5. Information regarding connection<br>6. Other data |
| Other | 1. Previous examination records<br>2. Previous maintenance work records<br>3. Condition of components<br>4. Other data |

## 4. System development

Taipei Confucius Temple's Yi Gate, built in 1881, was used to demonstrate the historic restoration timber building system proposed in this study.

### 4.1. System concept

The historic restoration timber building system comprises user interfaces, data management, and module management (Fig. 4), which are described in detail below.

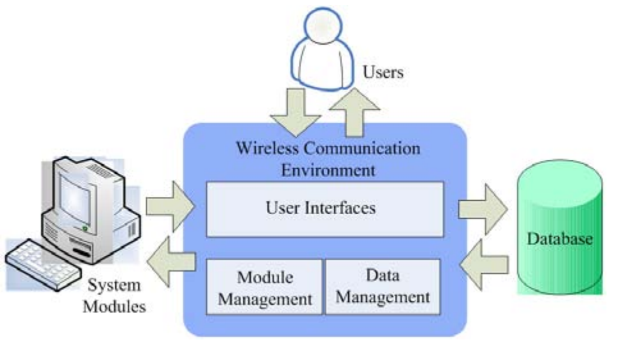


**Fig. 4.** System concept

1. User interfaces

A friendly user interface was designed by 3 kinds of dialogs, including Query-Answer, Menu, and Input/Output Form, to enhance effective user control of the system. Visual Basic was used to design computer and PDA forms, menus, and command and option buttons in a wireless communications environment.

2. Data management

Data were stored in a relational database linked to other databases. Structured query language (SQL) was used to manage component, schedule and drawing data. An MS SQL Server was used. Visual Basic performed middleware data management.

3. Module management

There were 6 modules developed for the client and server sub-system included:

(1) Client sub-system: RFID module for RFID tag data retrieval and storage.

(2) Client sub-system PDA operation module: for in-situ operation using a handheld PDA.

(3) Server sub-system project management module: to access project data necessary to support the decision-making process.

(4) Server sub-system restoration module: to record/retrieve useful restoration data.

(5) Server sub-system schedule control module: to assist with schedule planning and management.

(6) Server sub-system display and query module: to provide a friendly interface for users to select specific drawings.

### 4.2. System design

The historic timber building restoration system was developed comprising two sub-systems, i.e. client and server sub-systems (for PDAs and host computers, respectively), and wireless communications (Fig. 5). Prime system components, including Visual Basic, ArcGIS, and MS Project, were developed in an MS Windows environment. User interfaces were written using Visual Basic and Embedded Visual Basic (Fig. 6).

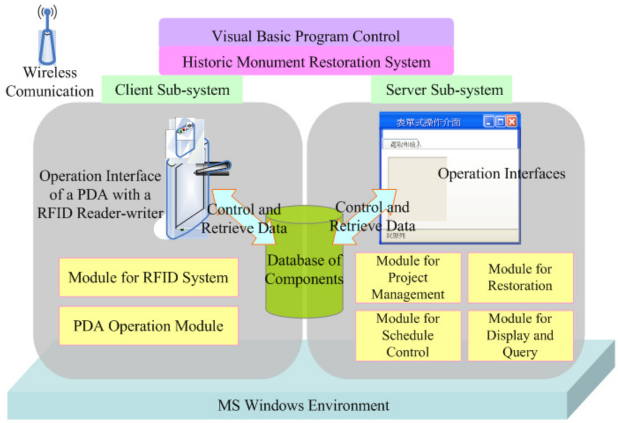


**Fig. 5.** System structure of functional modules

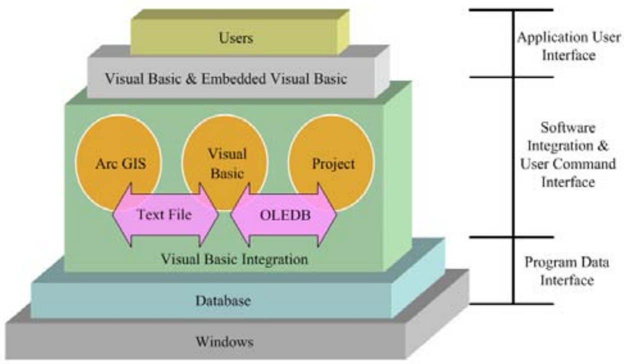


**Fig. 6.** System environment

#### 4.2.1. Client sub-system

In-situ engineers can use the handheld PDA with RFID reader-writer to enhance data collection efficiency, increase mobility and maintain data consistency. The functions of the two modules, which were developed in Embedded Visual Basic, are detailed below:

1. RFID module:
(1) Operate RFID reader-writer.
(2) Shutdown RFID reader-writer.
(3) Access RFID tags (read/write).

2. PDA operation module:
(1) File management: allows users to access, retrieve, delete, display, and manipulate related files, including those related to basic component data such as names, ID codes, positions, materials, damage conditions, restoration data (e.g. names of project engineers, dates, restoration methods used, storage sites, documentation responsibility) etc.
(2) Design display: displays associated drawings and data.
(3) Drawing-to-drawing query: this is a graphical query of detailed drawings. Users can double click on a particular graphic to perform a query. This feature enhances system flexibility by making it easier for users to access, retrieve, and display related graphic files.
(4) Drawing-to-data query: non-graphic files can be retrieved easily through a graphical query. Data retrieved assists in-situ engineers to identify storage areas, construction sequences, construction positions, construction schedules etc.

### 4.2.2. Server sub-system

A sub-system to help facilitate decision-making is essential for managers and planners. The 4 modules that need to be involved are described below. Each was developed in Visual Basic.

1. Project management module:
(1) Create a new project: project information includes scheduling data (*.mdb), types of drawing (*.shp), etc.
(2) Open a project: data is retrieved from the database.
(3) Delete a project: projects may be deleted from the project management module in accordance with the instructions of authorized officials.

2. Restoration module:
(1) Basic file management: files may be input or retrieved by double-clicking a specific component.
(2) Restoration data management: permits the management of data on engineers, dates of previous restorations, restoration methods previously used, storage sites, file management responsibilities etc.
(3) Synchronous transmission: permits database maintenance via wireless communication between the PDA and host computer.

3. Schedule control module: efficient schedules are planned using MS Project 2003. Schedule updating is done through uplinks to the database (Fig. 7).
(1) Project management: functions include new, open, delete, project information etc.
(2) Progress management: to view work progress in Gatt Chart and CPM formats.
(3) Schedule management: schedules are updated to reflect current restoration progress.
(4) Schedule analysis: to calculate discrepancies between actual and scheduled progress to assist managers to manage projects efficiently.

4. Display and query module:
This module was developed using MS Visual Basic and ArcGIS Engine, two commercially-available software packages. Drawings and data are two major components of the GIS. Each drawing is related to a set of data to describe its attributes through a one-to-one relationship (Fig. 8). Therefore, GIS is applied to obtain illustrations through drawing types by double-clicking on a graphic. The ArcGIS Desktop ArcInfo ArcTool Box is employed to deal with drawings by firstly transferring CAD map-layers (*.dwg) into ArcGIS files (*.shp) (Fig. 9).
(1) Basic functions: zoom in, zoom out, move, display, and whole (initial) view.
(2) Drawing-to-drawing query: select a particular drawing to retrieve related drawings.
(3) Drawing-to-data query: select a drawing to query related data.
(4) Construction sequence: query planned construction sequences.

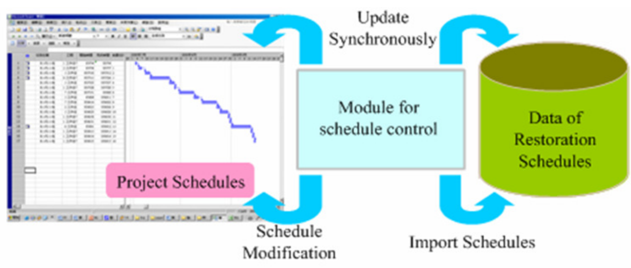


**Fig. 7.** Synchronous schedule maintenance

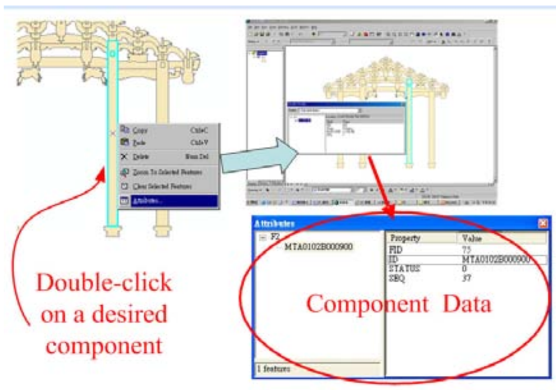


**Fig. 8.** Access component attributes

## 5. System demonstrations

The developed Taiwan historic timber building restoration system was demonstrated briefly by tableaux. The system, designed for use in Taiwan, uses Traditional Chinese as its primary user interface language. The two sub-systems were developed to run, respectively, on PDAs and host computers.

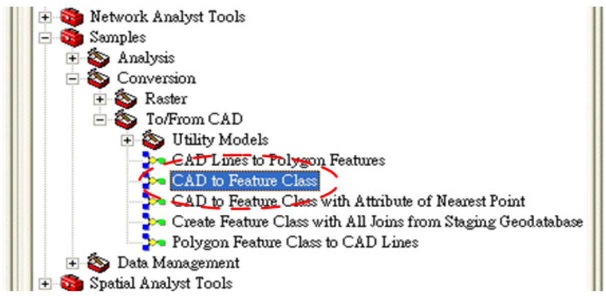


**Fig. 9.** Tool for map-layer transformations

### 5.1. Client sub-system demonstrations

The client sub-system was developed for PDA use with Embedded Visual Basic. The first page permits user login. Once logged in, a user is taken to the main page, which offers 7 optional links to the current (main) page, RFID/database connections, basic data, restoration data etc (Fig. 10). Excluding the main page, the 6 function options are shown in Fig. 11. In Fig. 11(a), the linkage page contains both RFID and database connections (including Access and SQL CE). In Fig. 11(b), basic and restoration data can be accessed, changed and updated. In Fig. 11(c), construction data can be queried by date. In Fig. 11(d), component schedules can be queried or updated by conditioning disassembly, restoration, and assembly phases. In Fig. 11(e) user queries may use basic zoom-in/out, shift and drawing-to-data functions. In Fig. 11(f) users can view lay down area data.

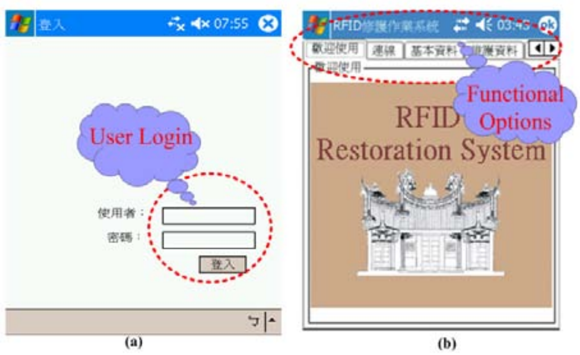


**Fig. 10.** User login page (a); main page (b)

### 5.2. Server sub-system demonstrations

The host historic timber building restoration system, developed with Visual Basic for the host computer platform, permits users to retrieve detailed data from the GIS-based host server. The first page requires user login using with a user-specific ID number and password (Fig. 12 (a)). After login, users choose a desired task (i.e. adding a new project, opening an existing project, deleting an existing project etc.). The main system page is shown in Fig. 12 (b). The 8 function options that can be selected include 4 basic interfaces ("basic data input", "basic data query", "restoration data input", and "restoration data query"), restoration schedule, graphic attributes, PDA transmission, and exit system. Button functions in the developed GIS-based system include graphic zoom in, zoom out, shift view, whole view, drawing-to-data, drawing-to-drawing, lay down area query, and delete data. Each component is numbered using a disassembly (assembly) sequence to assist restoration contractors (Fig. 13). GIS-based tools are used for map-layer displays, including functions of drawing-to-drawing and drawing-to-data for both plane and cubic drawing. Users can retrieve basic component data by double-clicking on any displayed component. Restoration data that may be input into the database include component storage and install location; whether a component is installed or not; the damage diagnosis; selected restoration methods and pictures before/after restoration (Fig. 14). Restoration data may be queried by component or date. When querying components by date, the schedules for qualified components will be displayed and segregated by colour to distinguish re-assembly conditions. MS Project is employed to handle schedules, which assists users to manage project work and progress (Fig. 15). Storage site maps may also be updated, and PDA communication functions are also provided.

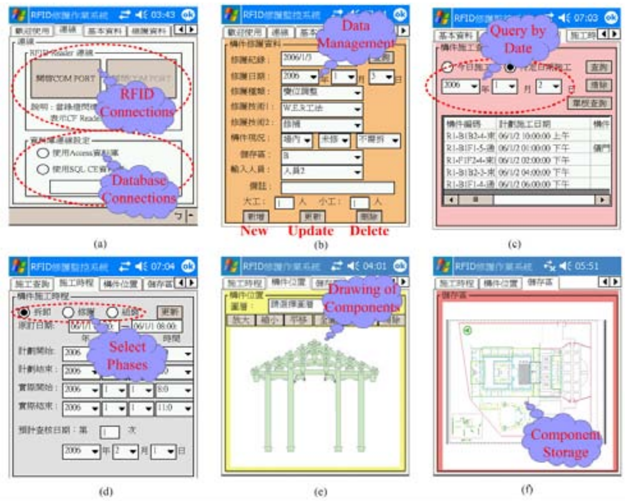


**Fig. 11.** Options: linkages (a); data management (b); installation queries (c); construction schedules (d); component displays (e); lay down area (f)


**Fig. 12.** The server sub-system: user login (a); main page (b)

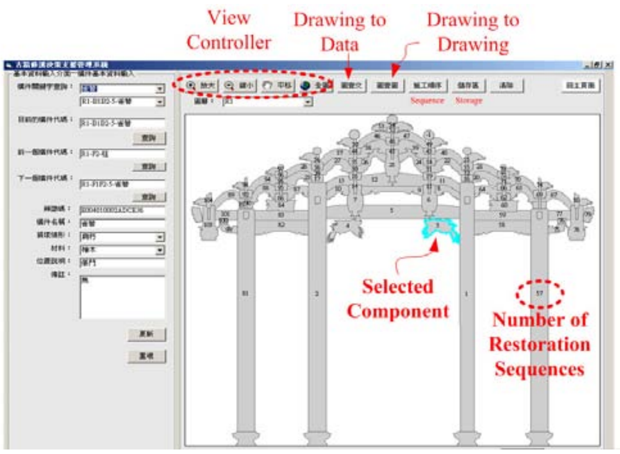


**Fig. 13.** GIS-based functions of server sub-system

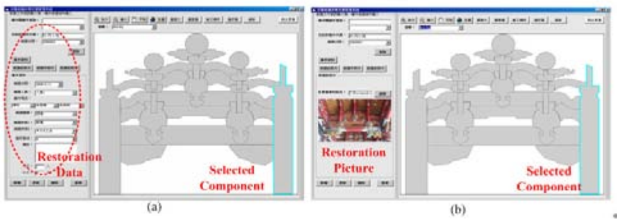


**Fig. 14.** Restoration information (a); restoration pictures (b)

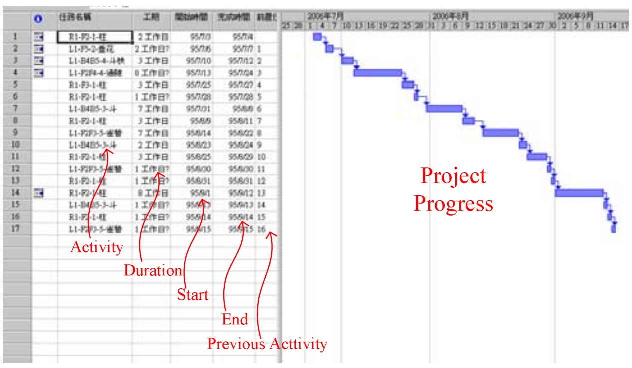


**Fig. 15.** Application of MS Project

## 6. Conclusions and recommendations

This study integrated RFID, IT, ArcGIS, and MS Project to develop a restoration management system for historic timber buildings that improved automation, efficiency, accuracy, and consistency. The developed system provides sufficient functionalities to assist managers and engineers in planning, design, restoration, and management. The major contributions of this study can be summarized as follows:

(1) Information correlation

A systematic management approach to building restoration work is urgently needed to handle critical data during the restoration process. To satisfy this demand, RFID technology is employed to transmit data efficiently and to improve data reliability. Users can access uploaded data at offsite offices or access real-time data onsite via radio frequency communication.

(2) Data records

Saving data in a database by a normalizing process can efficiently reduce data description redundancies. Also, the necessarily increasing amount of data over the service life of buildings makes the accurate recording and retrieval of data critical to successful building maintenance. The developed system allows for both the saving of useful data and recording of extended data. Data consistency can thus be easily maintained.

(3) Assistance to project managers

The GIS-based system provides a user-friendly and visually oriented query interface that integrates graphic and non-graphic information on the same page. It allows in-situ engineers and managers to retrieve data immediately. The component construction sequence can be retrieved to increase construction effectiveness. Furthermore, related data can be retrieved simply by keying in or selecting components.

(4) Applications to decision-making and evaluation

Information provided by the developed system assists users to manage and maintain historic timber buildings with restoration/examination schedules and reports. While restoration plans have been planned by managers, the developed system permits users to query which components need to be restored immediately or should be scheduled for restoration in the future. Also, historical data allows users to query which components have been seriously damaged in the past as well as the restoration frequency of individual components. Restoration techniques may thus be modified and restoration plans reevaluated based on this information in order to achieve improved results that reflect actual restoration needs and conditions.

In summary, the proposed system not only assists engineers to conduct their building restoration responsibilities, but also helps ensure that treasured historic buildings are properly maintained to continue standing and functioning indefinitely. This is the sincere wish of authors.

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## GIS PAREMTA ISTORINIŲ RĄSTINIŲ PASTATŲ RESTAURAVIMO SISTEMA TAIKANT *RFID* TECHNOLOGIJĄ

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S a n t r a u k a

Taikant geografinę informacinę sistemą (GIS) ir kitas technologijas, straipsnyje plėtojama informacinė valdymo sistema, integruojanti grafinius ir negrafinius duomenis, didinanti istorinių pastatų restauravimo efektyvumą Taivane. Sudedamiesiems komponentams stebėti realiajame laike taikomas radijo dažnių identifikavimas (*RFID*), taip didinant restauravimo valdymo efektyvumą. Saugomi *RFID* ženklių atmintyje restauravimo duomenys gali būti keičiami ir atnaujinami pagal specifinės restauravimo fazės reikmes. Taikant *RFID* delninius skaitytuvus gerėja tiek duomenų kaupimo efektyvumas, tiek sistemos mobilumas. Sukurtoje sistemoje rąstų statinio restauravimo duomenys ir piešiniai (brėžiniai) geografinėje informacinėje sistemoje gali būti iš karto pasiekiami kompiuteriniu tinklu ir taikomi restauravimo procese bei padėti strategiškai projektuojant, konstruojant, taip pat ir valdymo sprendimams priimti. Kiekvieno rąsto elemento duomenys, restauravimo seka, restauravimo vykdytojai, prižiūrėtojai, stiprybių galimybės ir kita gali būti pasiekiami nuotoliniu būdu su delniniu PDA skaitytuvu-rašytuvu darbo vietoje. Komponentų konstravimo eilės tvarkos išmontuojant ar sumontuojant duomenys gali būti sinchroniškai perduodami sukurtai valdančiai sistemai siekiant daug didesnio tikslumo ir patikimumo lygio, nei įprastai pasiekiama taikant tradicinius restauravimo valdymo taikymus.

**Reikšminiai žodžiai:** istorinių pastatų restauravimas, radijo dažnių identifikavimas, geografinė informacinė sistema, istorinis rąstų statinys, ArcGIS, sprendimų priėmimas.

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