Abstract. The paper reviews the development of city modelling and depicts the city modelling process for large-scale urban redevelopment. From an information mining viewpoint, the city model built has various levels of details and consists of street and building tags for identification, and the web-based interface is built for retrieving information and better understanding of the environmental changes as well as the progress of urban development. The demonstration and discussion are presented.

1. Emergence of 3D Digital Cities

The introduction of computer and communication technologies such as CAD, computer graphics (CG), photogrammetry, virtual reality (VR), web-based technologies, geographic information system (GIS) and global positioning system (GPS) has created doors for urban landscape visualization and information integration (Chiu and Lan, 2001; Sasada, 1999; Day and Radford, 1998; Ligget and Jepson, 1995).

There are different definitions and visions of digital cities varying from a real city to a virtual information city (Mitchell, 1994; Ishida, 2000). A 3D digital city is defined in this paper as a comprehensive, web-based representation, or reproduction, of several aspects or functions of a specific real city, open to all kinds of users. CASA (2004) at UCL in the UK has reported a survey of 60 digital cities in the world and found that various purposes, representations and technologies are applied. Apparently, 3D digital cities have become an alternative of city form and provide unique functions such as wayfinding, navigation and virtual visits (Morozumi et al., 2000). However, some key issues are inherited in the nature of creation of digital cities, such as: What are the values of city models? Who are the
users? How to utilize digital city models? How to receive feedback from its applications? More than a technical and practical issue, the digital city has dimensions that are social, cultural, political, ideological, and of course theoretical (Couclelis, 2004).

Our laboratory has developed city models of the Tainan city since 1996 by using different media for different aspects of urban studies, including 3D city models for the landmark visibility analysis and VR models for analyzing citizens’ walk-through behaviours (Lin and Chiu, 2003; Chiu and Lan, 2001). In recent years, we have created a city model for large-scale urban redevelopment. Therefore, a methodology of city modelling and the process of implementation are presented.

2. Methodology—An information mining viewpoint

City modelling involves huge information management, including image-based and text-based information. There are typically two approaches in constructing city models: (i) top–down approach, based on strategic decision to build integrated city models; (ii) bottom–up approach, aggregations of visual models of individual buildings, GIS data, traffic models, etc. (Day and Radford, 1998). We are adopting the top–down approach in the project presented because of the scale (large-scale urban redevelopment), user needs (Bureau of Urban Development) and time-effectiveness concerns.

In the field surveys of An-Ping, a historical district of the Tainan city, we built a 3D city model that represents the location and the functional type of about 50 landmark buildings and 2500 residential buildings. Currently, at least 12 new and renovation projects initiated by the city for urban redevelopment have been undertaken in the area. The users include city officers, planners, and citizens.

Generally, the city modelling process consists of data collection, validation, retrieval and updates. A digital city provides a metaphor of the real city and an

Figure 1. Aerial photo and the area of An-Ping for city modelling.
effective interface for browsing and inquiries. Apparently, geometric information can represent the city forms while city information consists of various important data. Aerial photos and digital maps as shown in Figure 1, are typically used as the starting point for data inputs. However, there is no reason to model the building already there, but planners need to catch key attributes abstracted from the form. Because the context and applications are as important as city modelling, we are more concerned about how urban form and the process modelling can be integrated. Therefore, an information mining approach for city modelling is initiated to reveal how data support user is reshaping the urban form.

3. City Modelling

Although city modelling is mostly related to the technical aspects, modelling should consider the existing environmental context as well as data availability because each city has its unique the characteristics. We consider the following issues of city modelling for large-scale urban redevelopment.

3.1. CAD OR GIS

Currently, there are three distinct approaches, based on different skills, to 3D city modelling, as reported by CASA (2004): (i) traditional 3D computer-aided architectural design; (ii) the engineering approach based on photogrammetric analysis and surveying; and (iii) geographic information systems. Apparently, CAD is mainly applied to construct and represent the urban form while GIS is applied to represent the attributes and statistics of cities. Because each has its strength and shortcomings, we are based on a Web 3D GIS system (Internet Map Server) to manage information while adopting various 3D models for visualization purposes.

3.2. DATA REPRESENTATIONS

A real city consists of various artifacts such as landmarks, buildings, and open space including urban plaza, streets and trees. A digital city model is composed of a number of different types of data: three-dimensional geometries of the study area; photo imagery data for realistic imaging of the site; and attribute data that is typically contained in a GIS system. Particularly in a large-scale modelling, both modelling and texture mapping are time consuming. Therefore, the representation can be pre-defined in accordance with the applications such as urban design or navigation. For instance, building geometries are essentially important for modelling in urban design, while textural mapping are only used for high quality visualization. As background or referential information, satellite and aerial photos are often used to enhance the quality of visualization outside of the simulated areas.
3.3. LEVELS OF DETAIL

The importance of defining levels of detail (LOD) has largely been discussed in previous literatures (Chiu and Lan, 2001; Day and Radford, 1998, Ligget and Jepson, 1995). The appropriateness of LOD in simulated area is related to the usefulness of the details and visualization. Ideally, each building is constrained to 20,000 polygons for optimizing visualization performance. In the An-Ping project, we had defined 4 levels of details. As shown in Table 1, each district is assigned to different levels of details according to the importance and needs. For example, at Level 1, the basic volume of buildings is configured with the height. Most residential buildings are assigned to Level 2 for general perceptions with basic building configurations including their elevation and roofs. For urban design purpose, Level 1 or 2 is applied for studying the massing and floor area ratio (FAR) as is evident in Figure 2. For photorealistic visualization, the higher level (Level 3 or 4) of details is assigned for modelling historical buildings with complete texture mapping. For instance, the area near the historical landmarks such as the Fort Zeelandia is assigned with the highest level to enhance the visual quality.

<table>
<thead>
<tr>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic volume by lofting (avg. floor height is 3.5m)</td>
<td>Level 1 + roofing + elevation with mapping</td>
<td>Level 2 + Ground level details (pedestrian) + balcony + elevation</td>
<td>Level 3 + Opening (windows, doors) + detail mapping</td>
</tr>
</tbody>
</table>

3.4. SCALE OF CITY MODEL

Generally, the size of the city model or database is critical and ways are needed to efficiently limit the data to be accessed and viewed (Ligget and Jepson, 1995). The new alternative is to subdivide the area with appropriate indexes and object hierarchies. The study area of An-Ping is about 100 square kilometres. Therefore, the area is divided into 6 zones to maintain the flexibility of modelling. On the other hand, the sub-area models can be integrated when needed.

While the LOD can be assigned to a specific area for visual analysis to optimize
the computing efficiency, we can define simulation areas more carefully in
accordance with urban planning policy or design criteria such as the mid-rise mid-
density scheme versus low-rise high-density scheme in a specific residential area.
Therefore, the adjacent areas of a target building can be defined and simulated as
shown in Figure 3. The foreground and background of the target area will be assigned
different LODs.

![Figure 3. Level of details applied to a building and a site.](image)

4. City Archive as a Data Warehouse for Urban Study and Design

City is a large man-made artifact and an evolving entity. City archive is an important
resource for urban planners and designers to study feasibility and visualize their
visions. City information is abstracted from the city archive for various purposes
such as city navigation, urban design, urban planning, etc. Particularly, different
users different in focus and intention to use data. Therefore, we can consider the
following factors for defining system interfaces.

4.1. TIME-SPATIAL RELATIONSHIPS

A real city can be represented with 1D, 2D, or 3D attributes. The digital model of
An-Ping is a 4D model, i.e. 3D plus timing. In the past 400 years, the original An-
Ping fishing village becomes a historical site containing plenty of small allies,
temples, residential buildings, landmarks and cultural heritages. At first, building
types are studied to define and model key elements such as the roof and openings.
Building models are gradually organized according to city sectors and building
types. In the modelling process, building styles and materials in different periods
are classified. Because An-Ping’s unique environmental characteristics were evolved
due to geographical, cultural and regulation changes, related information is collected
to describe the background and the prospects. Therefore, a real city is transformed
into a digital city as shown in Figure 4.
4.2. LAYERED CITY

Cities are considered as multiple-layered bodies of natural objects, artifacts and activities. For future urban development, different modeling layers related to urban planning and design are added and highlighted for users to examine. For example, places adjacent to landmark buildings or old trees, places near temples or plaza, old streets or waterfront can be specified for identifying the spatial quality. In order to analyze the structure of the area in view of citizens or visitors, we use different functional categories. With a specially developed model and GIS for visually representing those data, we succeeded in coming up with a micro-scale spatial structure of the area that explains spatial structures and the relationship with various activities. This model is not only aimed at representing visual aspects of a city but also to visually represent the invisible structure of a city, which might be interesting to urban planners as well as residents. More importantly, a city is a dynamic living body and the continuously developed activities within the city require a time–event tracing mechanism for searching the changes.

4.3. OBJECT TAGS

For cognitive purposes, users or residents require significant references or identifiers for wayfinding or navigation. Generally, city modeling can generate visual images,
therefore users can browse the images or navigate the 3D models. But these images or models often lack descriptive information or key identifications such as street or building names. This study proposes that key attributes of areas, streets, landmarks, and buildings will have object tags as identifiers to associate with related information where applicable. While moving through the scene, users can choose objects by using the mouse, as shown in Figure 4. When the angle is changed toward different directions, tags are enlarged or disappear.

In An-Ping, infrastructure such as roads and irregular streets are mixed with low-rise buildings and open spaces, and old and new buildings together. While these non-orthographic characteristics make the modelling complicated, tags becomes are useful for wayfinding.

4.4. INTERACTIVE INTERFACE

One of the merits of digital cities that differs from real cities is that the information can be represented in various ways simultaneously. This study proposes that information is generated for raising social interaction via a useful interface. Therefore, the interface is created for accessing information by a display panel/window on the web.

Furthermore, social agents in digital cities can support social interaction among residents and tourists (Chen et. al., 2004; Ishida, 2000). A navigational agent that can perform reactive or proactive human-computer interactions is tested for understanding the potential uses.

5. Implementation

To accommodate the digital content of city information including 3D models, a web-based GIS system with 3D capability, IMS (Internet Map server), is implemented. The goals of the system are two-fold: (1) to allow planners and designers to evaluate alternatives rapidly, in more detail, and for lower cost than through traditional analysis; and (ii) to make the results of the planning process visible, allowing the public to view the proposed environment in a realistic fashion. This system can be used both to identify existing problems and to quickly evaluate alternative solutions to those problems.

5.1. MIRCO VS. MACRO VIEW OF CITY MODELS

Urban design is concerned about the urban form and how it is made (Lynch, 1981). Kevin Lynch (1960) was concerned with the city as a social space and the ways in which we construct an internal cognitive model of the city. Lynch’s key concept was how users can construct a clear image or internal model of the city from the
perception of city properties. The main elements of the city images include path, edge, districts, nodes, and landmarks. These not only contribute to the image of a city but to its orientation. Although the imageability can be realized via visualization, residents or tourists tend to view the city from a microscopic view, while urban planners and architects tend to view the city from a macro view. Spatial information is therefore integrated into the city model from a street or a small district as a starting point, and then users can search upward to the building level or downward to the city level.

For example, Yen-Ping historical street used to be the first “market street” in Taiwan. The 3.5 km-long street consists of small shops and old buildings that form. Figure 5. Because it is located in the centre of the district, it is created to explore how users search relevant information.

![Figure 5. Information related to Yen-Ping Street.](image)

5.2. WHAT-IF SCENARIOS

The city model provides potential uses for different users. For urban planners, various “what-if” conditions are addressed in the urban redevelopment process. The web GIS system with 3D capability is implemented for answering the questions. All interfaces are implemented by C++ and javascript.

We are not only looking forward to modelling the current and the past of the city, but to its future development. Currently, at least 12 projects are under planning and some are under construction. We can pre-define the specific areas for updating, browsing and searches. To track the location of historical buildings or new constructions, a search interface is created. For example, the scenes currently and
after the renovation project near the Fort Zeelandia are shown in Figure 6. City officers and residents can compare the difference in these changes and the strategies. Similarly, different “what-if” scenarios such as how Floor Area Restriction (FAR) or building height is defined to certain area can be visualized and discussed by using the system.

Figure 6. Visualization of Fort Zeelandia before and after urban redevelopment.

5.3. USER QUERIES

In the system, query or search functions are becoming important for us to understand the needs as depicted in Figure 7. Each query about the system provides a hint for the potential use of the city model. We are accumulating the queries to evaluate information availability. To study the impacts of alternatives on visual corridors, viewpoints and view scopes are defined as shown in Figure 8. Based on the preliminary observations, we found that path edges, districts, nodes, and landmarks become the most useful settings for navigating areas. The imageability of the city via the system can facilitate urban planners in defining the urban planning guidance as well as the orientation of the city for residents and tourists.

Figure 7. Snapshots of query and 3D navigation

Figure 8. Viewpoints and view scopes.

6. Discussion

There is no absolute method for city modelling because city is a dynamic organism.
Our study provides a feasible approach to city modelling for urban redevelopment. However, there are still many issues, whether technical or social about how to conduct city modelling and evaluate the process. The foregoing study provides the foundation for the following discussions.

6.1. INFORMATION MINING VIA VISUALIZATION

Urban redevelopment is a situated and continuous process. When related new projects are completed, the city model is updated as well. To make the best of the city model and the system, the city model should be classified into a whole, partial areas, street blocks or single buildings for updates and searches. Urban planners generally apply visual analysis that requires the definition of visual observation points and the targets. Consequently, the city images generated from city modelling become an important metaphor for visual linkages of urban form and content. Furthermore, related information should be stored and linked for inquiries. Via visualization, the correlation among various buildings in the city archive is more evident by the data mining technologies.

6.2. THE INVISIBLE CITIES

Calvino’s (1974) famous novel Invisible Cities depicts multiple facets of a real city (Venice) in a dialogue format. An integrated city model is about making and understanding connections between phenomena, linking visual and non-visual, static and dynamic, description and the data (Day and Radford, 1998). By utilizing the city model, the implicit dimension of geography as well as culture and social dimensions can be further explored. For instance, a few An-Ping famous routes are selected to experience the narrow streets old houses, and more importantly, the life-style in the living environment.

6.3. USER FEEDBACK

The urban redevelopment process requires many efforts for communication and coordination for policy making and problem solving. “What-if” scenarios can be a straightforward way to demonstrate the alternatives and the usefulness of the city model. We are receiving feedback through group discussion and public hearings to define the priority of city modelling and media to deliver the city information. In current urban planning practice, the web GIS with city modelling complements the traditional analysis.

In summary, this is an ongoing project of foreseeing the past and predicting the future of the city based on our current understanding of the city. We are better understanding how to link physical and virtual worlds via the construction of a digital city. The methodological development is derived from the physical needs in
the process while technical implementation is incrementally solved with the assistance of GIS experts. The availability of the city simulation and data gradually influences the urban redevelopment policy and understanding of the users (city officers and residents).

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