World Transactions on Engineering and Technology Education
Vol.4, No.2, 2005

A preliminary study on building demolition engineering and management

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ABSTRACT: In recent years, building demolition has been challenging urban developers due to the increased incidence of demolition projects and the elevation of demolition requirements. The importance of building demolition is also recognised by researchers and, given its environmental impacts, it is anticipated to achieve the same attention as conventional planning, design, construction and maintenance in the near future. In this article, the authors aim to develop a series of strategies for promoting building demolition practice. Environmentally-friendly demolition procedures are introduced through a waste minimisation decision that makes the approach on alternatives to demolition and an integrated demolition planning and design approach focus on a just-in-time (JIT) philosophy. A conceptual management framework is also presented for the implementation of demolition projects.

INTRODUCTION

Building demolition represents the process in which an erected structure is purposely destroyed to form a diversity of components and fragments of mixed materials. From a lifecycle viewpoint, the demolition stage for buildings is achieved after the sequential stages of planning, design, construction and maintenance. The demolition process of a building is normally regarded as an unavoidable annoyance in its lifecycle and demolition contractors frequently undertake demolition practice with tight time constraints with little up front demolition planning [1].

The history of building demolition may be tracked back to several thousand years, including the effects from various ancient wars. Until the 1950s, buildings were mostly dismantled by hand at the ends of their lives due to structural or functional obsolescence [2][3]. For several decades now, urban redevelopment worldwide has led to the demolition of buildings that are still structurally and functionally acceptable. However, only in the last few years has the emphasis on demolition arisen, mainly due to increasing environmental pressure, particularly the disposal of demolition waste [4].

The importance of demolition is also learned from previous demolition failures and disasters brought about by the lack of sufficient awareness and knowledge on demolition. For example, demolition waste containing chemicals hazardous to human health and the environment may be sent to landfills, and the leachate from landfills poses a potential risk to groundwater quality [5]. Landfill creation is, therefore, an outcome that communities should seek to avoid due to the significant environmental issues involved. One disastrous example in Australia concerns the demolition of the Royal Canberra Hospital building in 1997. A girl was killed and at least nine others were sent to the hospital with serious injuries by flying debris when they stood in a designated viewing area 300 metres away [6].

Although a lifecycle approach has been considered to play an important role in project management by integrating all the above-mentioned stages, the last lifecycle stage of demolition has rarely been given full consideration. The demolition of an old building is normally dependent upon the development of a new project. Some old buildings and structures that serve no function at all may stand for years until a redevelopment is conceived and approved. The future of building demolition can be predicated by the availability and cost of new resources and by the scarcity of energy for machine operation, as well as by heightened environmental awareness [3].

However, previous efforts in both research and practice, such as setting up advanced recycling technologies for demolition wastes and improving landfill disposal technology, were mainly focused on the disposal of demolition waste, not the demolition process itself. As further improvements in demolition waste disposal are technically limited, the emphasis needs to be moved ahead towards demolition in the hope that an evolution of practice may one day provide an essential solution in order to radically lessen the waste disposal issue.

In this research, the authors seek to develop a series of strategies to promote building demolition evolution. The authors first describe the current circumstance of building demolition from various aspects. Then, environmentally-friendly demolition procedures are approached through minimum demolition waste decision-making via alternatives to demolition, and integrated demolition planning and design that is based on a just-in-time (JIT) philosophy. Furthermore, a conceptual framework is presented to highlight management issues during the demolition implementation stage. The research conclusions are stated in the final section.

PRESENT STATUS OF BUILDING DEMOLITION

Waste disposal from building demolition has become a challenging issue worldwide. In all states of Australia, the construction and demolition of buildings contribute up to 30-40% of solid waste that goes into landfills [7]. Therefore, waste can be reduced drastically if supply from the construction and demolition industries is limited. A major proportion of construction waste materials are collected for recycling rather than sent straight to landfills, as they are normally new and segregated. On the contrary, the indiscriminate demolition of buildings produces an enormous amount of mixed and heavily used materials that result in significant waste streams to landfills. Hence, it may be stated that demolition generates more waste sent to landfills than construction, although accurate data for their division from landfills or projects are unavailable.

Current building demolition is severely restricted by numerous factors, and its evolution by necessity must involve the demolition industry, regulations, economics, new technology, management and so on. The reduction of demolition waste will be achieved and benefit from a better understanding of demolition elements and the further establishment of an enhanced platform for demolition management.

Demolition Industry and Companies

It is apparent that the construction and demolition of a building functions oppositely. Construction and demolition are also interactive. Frequently, the construction of a new building requires the demolition of an old one or more on the site. There are also some examples in which the construction of a new structure is linked to the demolition of a historical one. However, the demolition industry is just a decentralised and diverse segment of the large and fragmented construction industry [1]. Only in large cities are there a few companies that are dedicated solely to demolition. One possible reason for this is that there are only a small number of independent demolition projects. In most cases, building demolition is immediately followed by new construction, and kept as brief and uncomplicated as possible.

The importance of demolition is completely underestimated because the materials and energy consumed in constructing a building dominate. In fact, manufacturers and suppliers of building materials are only the intermediate sources for construction, as the original source is nature, despite being largely invisible in the modern construction industry [8].

Demolition Regulations and Legislation

In Australia, several demolition regulations have been documented by government departments and professional authorities, such as Standards Australia and the Victorian WorkCover Authority [9][10]. In the Geelong region of Australia, the demolition work procedures include a demolition permit granted by a municipal building surveyor. However, compared to the construction regulations, demolition regulations are still rather separated, roughly-outlined and dated. For example, those demolition regulations given above were constituted from the occupational health and safety provisions with little concern on environment protection. There are no standards for demolition contractors; anyone with a backhoe can bid for a demolition project [1]. Furthermore, environmental considerations need to assume more importance in the process, particularly to the building owner, designer and contractor.

Research and development on building demolition have not drawn much interest from project managers or engineers, and no robust demolition code system has been published by any authoritative governments or associations. Moreover, some current legal regulations do not even promote environmentally-friendly demolition implementation. For instance, in the Victorian landfills in Australia, the difference of disposal costs per tonne between municipal solid waste and construction and demolition waste is only one Australian dollar [11]. The certification procedure for the quality of used building materials and components has not been well established and widely understood. Therefore, the salvaged materials and products are not easy to be approved and reused in the construction of a new project.

Demolition Economics

The abovementioned small number of demolition companies also implies low economic benefits of demolition projects. Current demolition cost factors retard the boom of demolition business [12]. These factors consist of the present low acceptance of recycled and reused components and materials, high labour costs, low tipping fees of demolition waste and so on. The salvaged materials market is currently struggling due to a secure economic climate, where the average home repair person, enterprise manager and urban developer can source new materials from a hardware store, rather than even considering second-hand materials.

The general consensus is that further education on environmental protection is required in order to drastically change this behaviour in society. The economics of demolition performance also drives demolition waste disposal decision-making. Any change in hauling costs, tipping fees and virgin material prices may induce the adoption of substitutive demolition and disposal methods.

Demolition Technology

Before the advent of mechanised demolition in the 1950s, demolition contractors brought very little materials to landfill sites and reused materials were widely applied in new projects as the hands-based *deconstruction* was commonplace as a demolition method [3]. Then machine-based dismantling became more common. The key reason to induce this shift was that the labour cost had increased faster than the equipment costs, despite the fact that greater recycling of used material significantly contributed to lower resource usage in new facilities.

Due to the time restrictions in preparing the ground for the construction of a new project, the demolition contractor frequently undertakes a demolition project with tight time constraints. Recycling is also out of the question due to the high labour content required and the difficulties to sort different materials unless it is specifically requested in the contract. So far, most buildings have been designed and constructed with no consideration of what will happen to them after their service lives, which also enlarges the difficulty in implementing careful demolition for recycling. Recent research projects have attempted to promote design for demolition [13]. As a result, a new generation of deconstruction based on the utilisation of machinery might be achieved in the near future so that a larger proportion of demolished materials can be reused and recycled.

Demolition Management

As an independent project, building demolition involves planning, design and implementation, as well as its unique issues, such as decision-making on alternatives to conventional building demolition, and the handling and disposal of demolition waste. With regard to the long-term ecological influences of demolition actions, the conventional machine demolition approach may be replaced by one of its substitutes. Technical development and research may enable those substitutes to become viable economically. The planning of a demolition project is generally based on the permission of demolition approved by a government department or authority.

The design phase of a demolition project focuses on the physical procedure of the demolition activities. The demolition implementation phase mainly relies on demolition technologies and project management principles. The following three sections of this paper introduce a series of proposed management strategies on decision-making for alternatives to conventional demolition, optimal demolition procedures with consideration to demolition planning and design, and a conceptual demolition implementation management framework. For simplicity, the disposal stage after the demolition waste generation is not elaborated on in this paper.

Figure 1 highlights the basic subjects required to be developed for promoting building demolition, including the development of demolition techniques and management, the enhancement of demolition awareness with owners, designers and construction teams, the development of environmental regulations on material consumption and disposal, and the quality certificates and market for reused materials and products to uplift demolition economics. The development of these practical subjects is interrelated and mutually promotional, and the developments in demolition management resulting from related research have direct effects on them. It is forecast that the improvement of these demolition-related subjects are also of a high benefit to the construction industry and the natural environment.

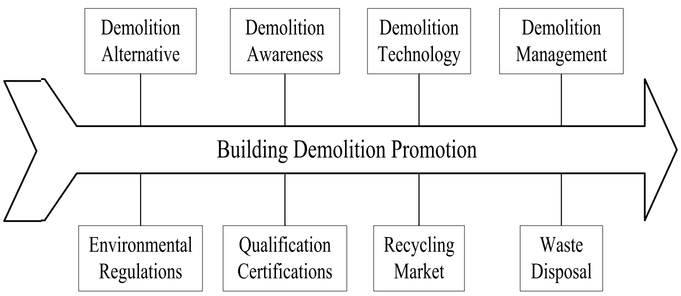

Figure 1: Building demolition promotion strategies.

ALTERNATIVE BUILDING DEMOLITION

Alternative Demolition Options

Buildings account for one quarter of the world's wood harvest and two-thirds of its material and energy flows [2]. From the viewpoint of natural resource reservation, the construction and demolition industries can use materials much more sustainable than they are doing now. Construction materials extracted from natural resources are sent to landfills after only one or two usages. As any natural resource is within limits after which irreversible or serious depletion and damage can occur, the resource extraction activities have to be undertaken with a view to the carrying capacity of the relevant ecosystem to absorb its varied effects [14].

To be more conscious of natural resources and more innovative in building demolition, there is a desperate need to find new ways of using no longer occupied or unwanted buildings. An example is that, in 2001, the Architectural Institute of Japan launched a design competition to extend the service life of a building to 100 years, over three times the existing design life of 30 years [15].

Although the currently widely-used machine demolition may be a quick, cheap and easy solution to remove buildings, other options under a systematic approach now more than ever need to be explored for the purpose of minimising construction and demolition waste. Figure 2 represents the construction-demolition chain from the raw materials extracted from the earth to landfill after one or more usages through construction and demolition activities. Building demolition alternatives decide the proportions of materials going back to construction through each of the loops from top to bottom as shown by the dashed lines.

An ideal solution for an abandoned constructed facility, which cannot be used as it is from a structural or functional standpoint, is to refurbish or relocate it. In this case, the life of a building is extended, and the majority of a building is retained. For many years, the renovation and rehabilitation of buildings in Australia has been developed under the requirements for building heritage preservation. An example is the Geelong Waterfront Campus of Deakin University, in which the whole building, originally built in the 19th Century, underwent extensive redesign and refurbishment in the 1990s.

Relocation has widely been applied on residential houses, particularly those with post and beam, weatherboard cladding and timber frames. In the Victorian region of Australia, more than 1,000 buildings are relocated each year [16]. Worldwide, successful relocation has occurred for bridges, churches, odeums and stations, plus other structures. After refurbishment or relocation, as shown in Figure 2, a building may be of service again with the original – or a modified – function.

In addition, buildings that are optimally designed with environmentally sustainable materials and with deconstruction in mind are of extreme value for reducing waste, although most buildings currently being refurbished or totally demolished are not of this nature. Deconstruction is the first consideration from an ecological viewpoint if demolition has to be carried out.

By deconstructing the building, the reuse of materials would provide the next best result following refurbishment or relocation in terms of waste minimisation. Destruction, which represents machine-based dismantling, may still allow a major portion of the material to be recycled and reprocessed into building elements. The last process in order of preference is the disposal of the demolished waste to landfill, which should only occur after all other options have been fully explored and investigated.

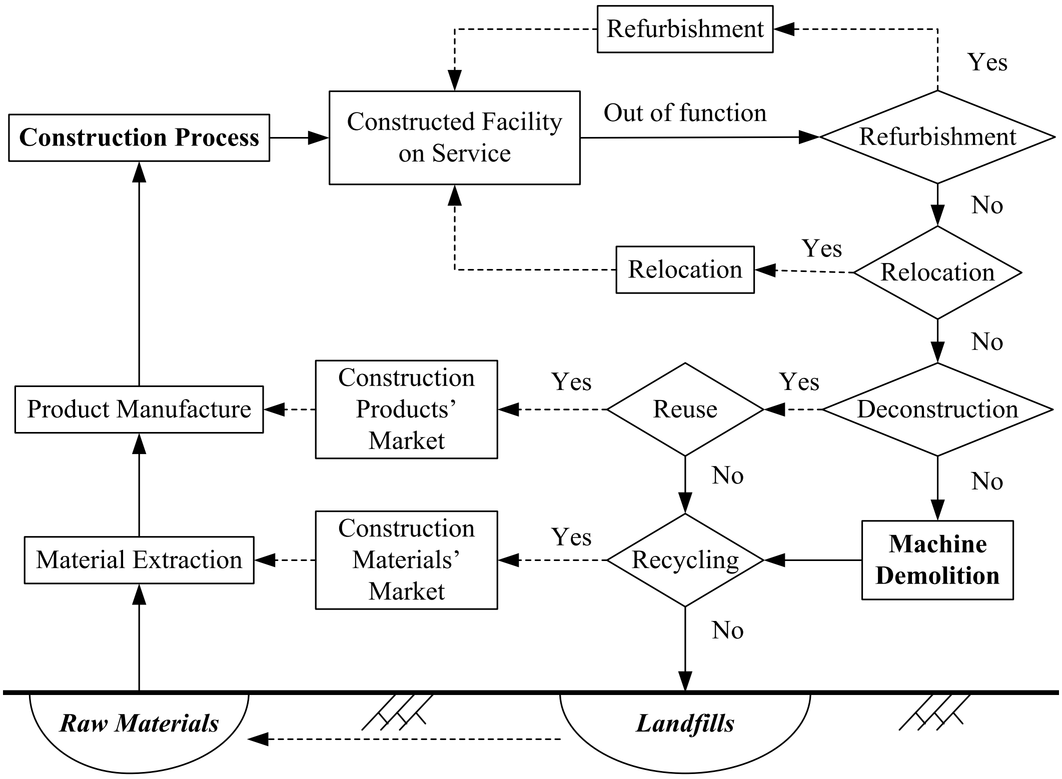

Figure 2: Decision-making process on building demolition.

Economic Analysis of Alternative Demolition Options

This optimal decision-making process on alternative approaches implies the maximisation of resources conservation by preventing demolition waste in the first place, such as by extending the building's life or the optimal design of the building for reuse. Minimum waste-oriented demolition processes also provide a systematic approach to reduce landfill pressure from the construction industry. The economic performance of each demolition method may be analysed and compared.

Based on a real case study, research was carried out to depict both the economic advantages and disadvantages of three demolition strategies, which are as follows:

- Machine demolition;
- Machine demolition for recycling;
- Deconstruction [12].

The base case for comparison was traditional machine-based demolition. The main cost factors considered were labour costs, materials benefits, plant costs, environmental costs and administrative costs. This previous study may be extended to define and model all demolition and alternative scenarios with an emphasis on refurbishment and relocation.

Each scenario may further be evaluated holistically using a combination of multiple criteria, like financial returns, functional performance, energy usage and environmental impact criteria [17].

INTEGRATED BUILDING DEMOLITION

Conventional Demolition Procedure

Compared to a construction project, the demolition of a building is being conducted under a relatively ungoverned circumstance with few planning and design activities. From the viewpoint of project management, it is ideal if demolition activities are considered before the completion of construction, but a real-life building is hard to be demolished in this manner due to the uncertainties of its long life. In fact, most existing buildings are not designed or constructed by taking demolition into consideration. Therefore, planning and design are required once a building demolition project is identified. Due to various reasons such as insufficient time, demolition planning and design is disregarded in current demolition practices.

Figure 3 describes the conventional building demolition procedure. Demolition preparation starts from the application for a demolition permit granted by a local municipal building surveyor. Planning briefly sketches the demolition procedure and techniques involved. In the conventional demolition procedure, waste collection and classification takes even more time than the demolition process.

All waste exchange activities that enable waste reuse and recycling happen after demolition implementation. Before the demolition materials are physically generated, there is no communication between waste material producers and demanders. The waste materials are likely needed to be reworked because they do not satisfy the demanders' anticipation. Therefore, under such an inefficient demolition procedure, the goal of waste reduction is very hard to achieve.

Currently, there is little consideration to put demolition design into practice. Project contractors simply use heavy machines, explosion or implosion to destruct the whole building structure for simplicity and convenience. The leftover of such activities is a mixture of all kinds of construction materials. This approach makes the useful materials so difficult to be classified that they are rarely reused in other construction projects. Instead, they are usually disposed to landfill causing environmental damage.

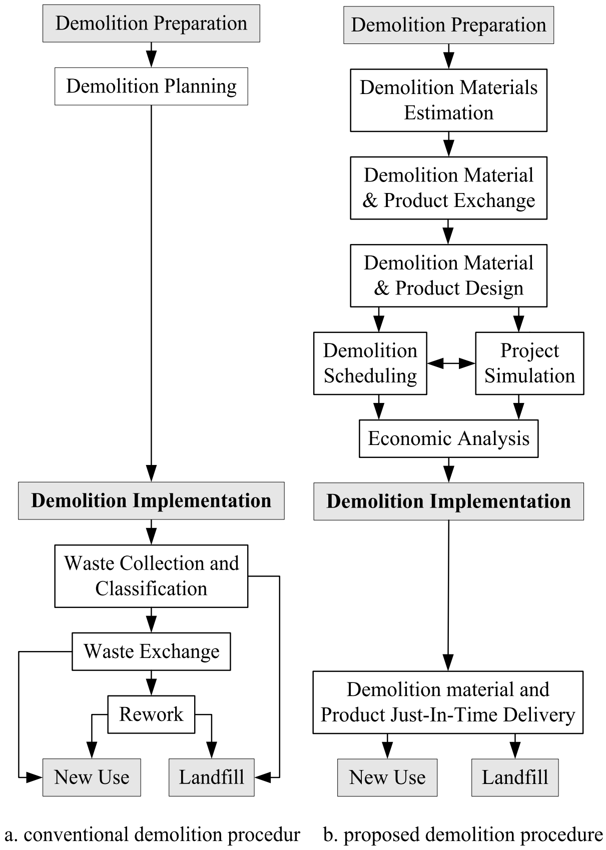

Figure 3: Conventional and proposed demolition procedures.

Even though some demolition materials can be salvaged and separated, they are very likely to be reworked to meet the requirement of the buyer due to a lack of communication before demolition activity commenced. For example, wood might have been truncated into one-metre lengths, while the buyer needs two-metre lengths. In this conventional approach, apart from the large amount of useful materials being sent to landfills, the building owner needs to pay for their transportation and disposal. In another words, the value of useful secondary materials is wasted due to the conventional demolition procedure.

Just-in-Time (JIT) Philosophy-Based Demolition Procedure

Figure 3 also presents an improved procedure for building demolition. The conventional and proposed demolition procedures differ in the order of demolition design and waste exchange. Applying the proposed demolition approach, the demolition procedures of a project need to be changed substantially. Adopting the proposed approach into demolition implementation can strongly refine the demolition procedure and release the negative impact of building demolition on the environment.

On the other hand, the proposed demolition approach is a benefit-driven procedure. Demolition project decisions are made based on the explicit benefit(s). Various types of benefits may be weighted and scored to make an overall decision, such as whether a project team should adopt deconstruction or destruction, and what the strategies and techniques are to be used in demolition. In the proposed demolition procedure, once a building is decided to be demolished according to the owner's requirements, the first working step is to estimate the potential wastes and publish them under a Web-based demolition management system so that the public can access the demolition information [18]. In this way, the potential material demander can be found and more conversation or negotiation can be made between providers and buyers of the used materials. This is particularly helpful when a buyer has some special requirements for a material or product. These requirements such as price, amount, quality and dimensional specifications of waste materials can be recorded to generate a formal specification for both the provider and buyer.

Benefit analysis reports automatically notify the owner of the building to be demolished the financial benefit and the environmental benefit from the demolition project. These specifications and reports then play an important role in demolition design and implementation. Under such a circumstance, demolition activities are made similar to a productive process to manufacture products for consumption by others. According to the demolition design, the amount and classification of waste materials can be finalised and scheduled.

Finally, waste products can be delivered to buyers during the demolition project implementation according to the demolition schedule and hence deposit or storage can be avoided.

Looking through the production, transportation and consumption of the waste materials, building demolition can be regarded as a form of just-in-time (JIT) production, where waste materials are not waste in the traditional sense, but products carrying business values for the next usage [19]. The wide understanding and acceptance of JIT demolition can benefit all parties involved directly and indirectly, including demolition project clients, demolition firms, recycling companies, and second-hand material and product demanders. In addition, JIT demolition may release the landfill pressure drastically, and also preserve natural resources to be mined in the future. Zero emission may be difficult to achieve in building demolition, but the maximum waste utilisation derived from a JIT application will degrade the global environment least.

Demolition material exchange is generally an information exchange process between wasted material producers and demanders. The Internet is an ideal platform to perform such an information exchange and a number of Web-based systems have been developed for waste exchange. However, under a conventional demolition procedure, most current waste exchange Websites could not attract enough users [20]. In order to best utilise demolished materials, demolition materials and product exchanges must be conducted *before* the constructed facilities become waste by the machines. This means that the objective of exchange in the proposed demolition procedure is the demolition project instead of demolition waste. In addition, a Web-based information system can be developed to deal with waste estimation and transportation handling besides waste information exchange.

BUILDING DEMOLITION IMPLEMENTATION

Similar to the resource requirements for constructing a project, in order to demolish a project, a diverse group of people have to come together, and divergent materials or components change their shapes, functions and positions, and specially developed machines act in a large three-dimensional space.

Demolition also contains unique management constraints due to strict environmental protection requirements, potential emergent issues, uncertainty and so on. The management issues during the demolition implementation stage require wider consideration, which may include demolition cost estimation, quality control, resource allocation, site layout, progress monitoring, waste handling, and so on. Figure 4 describes a demolition management map through an incomplete jigsaw puzzle. Some pieces of the jigsaw, entitled demolition database development, demolition scheduling, and demolition project simulation, are described in the following sections.

Demolition Product Database

The general demolition information of a project has to be captured from several sources including the building owner, estate agency, and the demolition engineering team. A database needs to be developed as an information hub for controlling demolition project implementation and handling demolition product delivery. The purchasing requirements from the consumers are the essential information to determine the demolition products that are a key part of the database.

As the demolition components of a building are not as detailed as construction components, the relatively brief architectural design code system may be used to draft a demolition code system. This code system is used to represent all building components, including those that are sold and those that remain. Data related to each demolition product can contain all the resource requirements for materials, machines, workforce, budget, time and space. For each demolition product, a database table is needed to record all the geometrical data visually as well. The precedence relations among the demolition products are also recorded in the table. The resource needs and operational durations are then calculated.

Demolition Process Scheduling

Demolition process scheduling is the preparation of an ideal demolition schedule in which each demolition product is allocated with one or more demolition processes in one or more time intervals. Demolition schedules may be product-oriented or process-oriented. Both product planning and process planning can be scheduled using a scheduling tool and various resources can be analysed and reported under it.

The demolition process representing the dismantling activities is strongly dependent upon the building structure and the site environment. The principles of network analysis are utilised to determine and optimise the whole building demolition schedule. The technological and environmental precedence relationships of the dismantling process can be illustrated using a topologically ordered activity-on-node network, in which the nodes represent the dismantling activities and the arcs represent the precedence relations among the activities. The optimal demolition schedule is then presented in bar charts in order for it to be easily understood.

Similarly, different dismantling activities have to be defined according to many variables, including the type of building to be demolished, the dismantling techniques available, and the objective of the final products. Different environmental constraints, such as obligatory levels of separation, also lead to different dismantling activities. After the dismantling activities are determined, the resources necessary and the duration of the activities need to be specified in detail. The differing dismantling techniques and arrangements result in altered disposal costs and environmental impacts. So far, no methodology has been developed to estimate the resources needed for each demolition process, and discussion with engineers and front workers in demolition companies may turn out to be the main means used to obtain such data.

Demolition Project Simulation

The availability of demolition process scheduling relies heavily on the abilities of project participants. Compared to construction, demolition scheduling is more demanding in time, space, safety and environmental regulation. Furthermore, due to a lack of engineering experience and theoretical

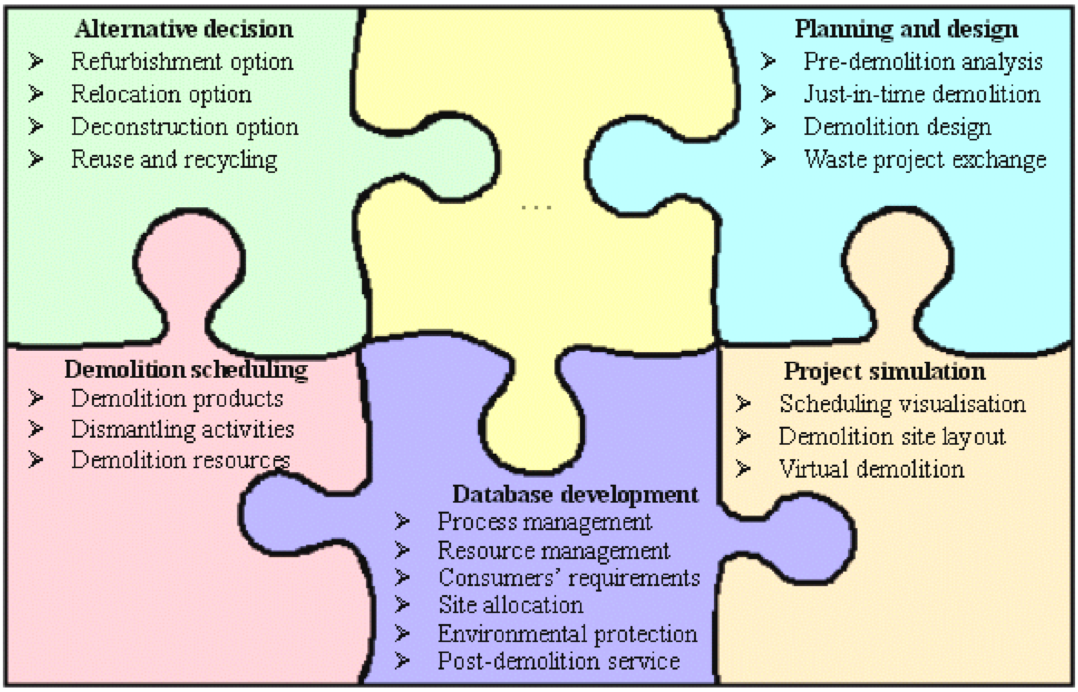

Figure 4: A map of a building's demolition.

knowledge, rational demolition scheduling is more difficult to generate for a practical project. Therefore, a virtual demolition simulation effort in advance of the real demolition is particularly useful for the demolition process in practice.

The development of an electronic technique for demolition scheduling is also conducive to spreading awareness of demolition in practice. As the digital drawings of most buildings to be demolished are not documented, a three-dimensional model following the same demolition code system used in the database development needs to be prepared for visualising the demolition implementation over time. By connecting the three dimensional model and the database, the data of each demolition product recorded in the database can be visualised over time in the drawing environment. Both the demolition process and the project site availability can also be visually simulated so that the demolition products may be generated and delivered according to consumer requirements.

CONCLUSIONS

Serious attention has been drawn to the demolition of buildings due to the enormous amount in landfill disposal being generated globally. The current demolition approach gives little time to demolition participants from the occurrence of a demolition concept to the implementation of demolition activities. In this paper, the authors present the promotion strategies for demolition from the viewpoint of systematic demolition management. Based on this research, the following conclusions can be stated.

The demolition stage in the lifecycle of a building is of the same importance as planning, design, construction and maintenance stages.

The demolition waste dominates the waste stream to landfills and hence minimising the demolition waste is a crucial strategy to develop environmentally friendly building techniques.

A series of demolition management strategies was set up for reducing demolition waste sent to landfills from decision making on alternatives to demolition and demolition planning and design, to its actual implementation.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge Deakin University for providing funding through a Central Research Grants Scheme to support this research effort.

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