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Building Reuse Assessment for Sustainable Urban Reconstruction

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Keywords: Foundations, Sustainable Development, Urban Development, Rehabilitation, Urban Renewal, Pile Foundations, Renovation, Demolition

OUTLINE FOR BENEFIT OF REVIEWERS

I) INTRODUCTION

II) BACKGROUND

III) BENEFITS OF BUILDING COMPONENT REUSE

    A) Sustainability

    B) Direct Cost Savings

    C) Indirect Cost Savings

    D) Additional Benefits

IV) METHODOLOGY

    A) Above Ground Structure (AGS)

    B) Basement

    C) Foundation

V) THEORETICAL QUANTIFIED COST SAVINGS

    A) Reuse of Foundation Only

    B) Reuse of Basement and Foundation

    C) Reuse of AGS, Basement, and Foundation

    D) Quantified Cost Summary

VI) CASE HISTORIES

VII) CONCLUSION

Abstract showing relevance to practitioners

Building reuse is a linchpin to managing solid waste. Despite the various benefits beyond contributing to sustainability that can be realized through building reuse, including direct and indirect cost savings, truncated construction schedules, and reduced site disruptions, little formal consideration has been given to this topic, which places professional engineers at disadvantage, when considering this as a design option. As each building project has its own specific requirements, reuse is not always the most economical solution, however, but in cases where reuse is in part motivated by other factors such as heritage protection, substantial economic and environmental savings can be realized in tandem. In this paper, a generalized assessment method for reuse is presented to facilitate benefit maximization, and the costs related to building replacement and sustainable reuse are compared using two case histories and a theoretical building. A clear correlation is shown as to potential for savings as a function of project size, with a theoretical project offering savings from 4-65% depending upon how much of the existing structure is retained.

Paragraph showing relevance to practitioners

When the design life of any building has expired, it must be either renovated or replaced. Often times, sustainable solutions are overlooked in favor of traditional options that were once definitively more economical. With advancing technologies, alternative solutions are increasingly becoming economically competitive. Total or partial building reuse is a solution that contributes to both direct financial gain and environmental sustainability. Each project offers a different potential for reuse, causing some to be more amenable for partial reuse. Within this paper, one of two case histories demonstrated that renovation can be an economical, as well as an environmentally sustainable solution. Additional benefits to direct cost savings include an abbreviated construction schedule, reduced liability, decreased impacts to surrounding facilities, as well as many enhanced environmental sustainability. The assessment procedure presented should be implemented to most effectively determine the reusability of a building and to realize the affiliated benefits.

Building Reuse Assessment for Sustainable Urban Reconstruction

Debra F. Laefer, M. ASCE,[1] and Jonathan P. Manke[2]

ABSTRACT

Building reuse is a linchpin to managing solid waste. Despite the various benefits beyond contributing to sustainability that can be realized through building reuse, including direct and indirect cost savings, truncated construction schedules, and reduced site disruptions, little formal consideration has been given to this topic, which places professional engineers at a disadvantage, when considering this as a design option. As each building project has its own specific requirements, reuse is not always the most economical solution, however, in cases where reuse is in part motivated by other factors such as heritage protection, substantial economic and environmental savings can be realized in tandem. Based on nearly two decades of professional experience, a generalized assessment method for reuse is proposed to facilitate benefit maximization. Applying this 10 step method, the costs related to building replacement and sustainable reuse are compared using two case histories and a theoretical building resulting. A clear correlation is shown as to the potential for savings as a function of project size.

KEYWORDS: Foundations, Sustainable Development, Urban Development, Rehabilitation, Urban Renewal, Renovation, Demolition

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INTRODUCTION

The rapid technological developments and higher standard of living in the 21st century are surpassing the environment's ability to replace consumed resources. To contend with these trends, sustainability must become an integral part of all industries. To achieve this, many criteria have been proposed, in which solid waste management is a key issue (e.g. Brugmann 1992, ORTEE 1992, and Baetz and Korol 1995). Solid waste is increasingly being used as a prime indicator to monitor sustainability (Horwood 2005, Fung and Kennedy 2005, Agyeman and Evans 2003), but much of the focus has been on trash pick up and recycling (e.g. DiNino and Baetz 1996, Georges 2006, Baetz and Korol 1995) with insufficient attention paid to the construction industry, where construction and demolition (C&D) debris make up an estimated 10 - 30% of total landfill waste in both the United States (MSU 2003) and abroad (Maydl 2004). In HUD's most recent investigation (HUD 2003), construction related debris annually represented approximately 136 million tons of waste, nearly half of which was from demolition (Fig. 1).

Ireland provides an example of the importance of this issue, where over 90% of non-agricultural waste is C&D waste, which translates to over 7 million metric tons of waste per year for a country of barely 4 million people (Forfas, 2005). The repercussions of this scenario is an anticipated filling of all available landfills in only three more years (DLRCOCO, 2005) and the planned introduction of highly controversial incinerators for the first time in the country's history (Davies 2005), because the government predicts that an inability to absorb solid waste will cause severe operational problems for companies in the industrial and commercial sectors, with knock-on effects for economic competitiveness (Forfas, 2005). Building reuse is a logical area in which to counter this trend (Chung and Lo 2003). Although life cycle assessments are well in place in some industries (e.g. McDougall and Hruska 2000) and is increasingly

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understood as a key component to sustainability management plans, buildings today are designed with only a single programmatic scheme and no end of use plan.

Building reuse as an alternative to demolition offers reduced debris generation, maximized material reuse, and minimized resource consumption. The extent of sustainability that can be achieved, however, is inherently influenced by the viability of reuse of each portion of the structure. The purpose of this paper is to propose an assessment procedure for both above- and below-ground structures, and to demonstrate the potential cost benefits attained, when reuse is pursued. Actual case histories are included to show some of the complexities of comparative economic analyses and to illustrate the function of building size as a potential predictor for cost savings.

BACKGROUND

Buildings are designed for a specified working life, at the end of which a decision must be made as to the building's future. The life-cycle expectations for a building generally do not exceed 50-60 years (Chapman et al. 2002). After decades of use, a building may no longer meet the programmatic needs of its occupants. If complete demolition of an existing building is deemed to be required, then the reconstruction of both above- and below-ground building components is necessary. While above-ground reconstruction tends to be straightforward, below-ground reconstruction may be highly complex. Many older cities, especially in Europe, are finding that below ground, urban reconstruction is increasingly difficult and expensive, as the ground is crowded with utilities, transportation tunnels, and foundations from previous buildings (Chapman et al. 2001, Chow et al. 2002, Katzenbach et al, 2003). This ever-increasing congestion makes foundation and basement installation difficult and the removal of obstructions expensive and time consuming. With replacement becoming more cumbersome and costly, and renovation appropriate for only a limited number of buildings, a suitable solution may be partial building reuse.

BENEFITS OF PARTIAL BUILDING REUSE

The extent to which the benefits of sustainability can be realized is directly related to the percentage of the building being reused. The maximum benefits of sustainability should be the goal for all projects, however, environmental benefits can still be achieved through partial reuse. While partial reuse can benefit all projects, the most clearly advantageous situation for building reuse is in urban environments, where sites may be in premium locations, real estate costs tend to be high, and new construction can negatively impact nearby structures (Chapman et al. 2003). The main benefits of building reuse include sustainability, direct and indirect monetary savings, an accelerated construction schedule, and decreased liability exposure (Fig. 2).

For existing buildings, there are three major components through which to realize reuse: the above-ground structure (AGS), the basement, and the foundation (Fig. 3). The AGS includes everything, except the first floor slab, the basement, and foundation elements and typically comprises the majority of the working, living, or retail space. The basement may act as the foundation (similar to a slab on grade) or as a means of load transfer from the AGS to the foundation, or there will be traditional shallow or deep foundations to transfer the building loads to the soil. The benefits to reuse of each part of the building are described below.

Sustainability

The benefits of energy savings and material conservation are similar in nature for the reuse of the AGS, the basement, and the foundation. Avoiding the demolition, removal, and reconstruction of the existing building precludes energy expenditure and landfill-contributing waste generation (Chapman et al. 2002). Additionally, as the various reused components become the basis for the new building program, consumption of new construction materials is reduced. Sustainability is, therefore, partially achieved as material reuse is maximized and resource utilization and waste production are minimized.

Direct Cost Savings

The direct cost savings resulting from building reuse can be considerable (Fig. 2). Labor costs are drastically reduced by minimizing the work related to demolition, reconstruction, new material transportation, and waste material disposal. Substantial savings can also be realized through material cost reduction, as the materials of the reused portion of the existing building circumvent replacement, thereby decreasing the need for new materials. Basement and foundation reuse also substantially contributes to direct savings, as excavation is minimized, and the significant cost of excavation support is reduced. Additionally, the substantial fees associated with the disposal of both demolition and subsequent new construction debris is minimized.

Indirect Cost Savings

Other benefits are the indirect cost savings, mainly from a shortened project length. By avoiding removal and reconstruction processes, the schedule is reduced, and the exposure to construction delays, accidents, and other construction-related liabilities is minimized. For both owner and contractor, a lengthened construction schedule represents direct financial loss. Some of these savings, however, may be offset by the building's functionality continuing to be dictated by its old geometry and unknown conditions of existing materials.

Additional Benefits

The minimization of noise, construction pollution, and other nuisances related to construction activities is an additional benefit resulting from building reuse (Fig. 2). By reducing demolition and subsequent reconstruction, noise can be significantly reduced. A shorter construction cycle also decreases the general nuisances and disruptions. Similarly, debris and pollution can be minimized.

Basement and foundations reuse offer improved constructability and soil performance. Subsurface conditions crowded by utilities, tunnels, and previous construction can complicate foundation removal and installation processes, with attendant delays and costs. Additionally, basement- or foundation-induced clay heaving and settlement is largely avoided (Fig. 4). Removals can affect a new foundation's capacity (Chapman et al. 2001), and despite the use of excavation support, can lead to the damage of existing, adjacent structures. Also, during foundation removal and subsequent new construction utility relocation may be required. With basement and foundation reuse, more of these utilities can remain in their current locations, thereby minimizing service interruptions.

METHODOLOGY

To maximize sustainability and optimize potential benefits, a basic assessment procedure is needed. Based on the aforementioned benefits, such a method is proposed in Figure 5.

Above Ground Structure

A sustainability assessment begins by considering the condition of the AGS (Step 1). If the AGS is in a reusable condition, the adequacy of the exterior and interior geometry must be assessed against programmatic needs (Steps 2 and 3). If either geometry is insufficient, alteration must occur. To alter the exterior geometry, the site must be capable of accommodating expansion (Step 2a). Typically, urban sites have little room for expansion because of the crowded nature of urban settings. In some instances, the original building does not occupy the entire site and expansion is possible, if zoning permits.

To alter the building's interior geometry, a transfer girder can be incorporated (Step 3a) to supplant previous interior structural elements and achieve large, unobstructed spaces (Fig. 6). Such is the case in the adaptive reuse of many older buildings from multi-unit facilities to large retail spaces. If neither interior nor exterior alteration is feasible, the AGS must be demolished. Also, the AGS must be capable of carrying the new loads (Step 4). If the AGS is incapable, the AGS must be removed, or extensive intervention must occur (Step 4a), similar to that necessary for seismic retrofitting.

Basement

Irrespective of the AGS's future, the basement is considered next (Step 5). Its space and geometry must be adequate for new usage requirements (Step 6), as well as its load carrying capacity. If these are in anyway inadequate, alteration must be considered (Step 6a). If impractical, then both the basement and AGS must be removed, and sustainability can only be realized through foundation reuse.

Foundation

The removal and subsequent replacement of the AGS (and basement) causes the foundation to experience first unloading then reloading, thereby generating possible additional settlement caused by soil relaxation (Mitchell 1993). If new loads do not exceed existing positional loads, foundation reuse can proceed (Step 7). If the new building is larger, or more typically with less column lines (RUFUS 2006), anticipated loads will tend to exceed previous loads, and existing foundation capacity must be evaluated (Steps 8 and 8a). Inadequate foundations must be increased (Steps 9 and 9a). If, with improvement, the foundation can be reused, then savings from reuse can be realized (Step 10). If no foundation improvement method is found to be practical, none of the building can be reused, resulting in no cost savings and no sustainability benefits.

THEORETICAL QUANTIFIED COST SAVINGS

To evaluate the potential cost savings from partial reuse, three main combinations of building component reuse should be considered: 1. foundation, basement, and AGS [Fig. 7 (a)]; 2. foundation and basement, [Fig. 7 (b)]; and 3. foundation only [Fig. 7 (c)]. Because partial building reuse is directly dependent on the lower components, the cost benefits will be analyzed from the subsurface upwards.

While a generalized cost analysis would offer the most applicable results, the generalization of cost savings from building component reuse is hampered by the variability of materials, location, and style of each building. Because of this diversity in structures, a prototypical 1960's urban office building is analyzed to illustrate the potential savings obtainable through reuse. The theoretical building consists of a 12.8 m wide by 21.34 m long, 10 story, steel-frame AGS, a 3.66 m deep basement, and a pile foundation consisting of 56 piles in 8 pile groups. Additional properties of the prototype building are listed in Table 1. The building loads consist of dead loads of 3.35 kPa per floor and 1.44 kPa for the roof with live loads of 2.4 kPa per floor and 0.95 kPa for the roof (ASCE, 2003). The future programmatic needs consist of a 50% increase in working space, leading to a 50% load increase. In the following sections, the cost for the removal, replacement, and enhancement related to each building component is explained and quantified, based on this theoretical building. The costs related to the removal and replacement processes are listed in Table 2, and the costs related to enhancement are presented in Table 3. Additional costs can be incurred by the building's users, if the construction processes cause work disruptions to the occupants. These disruptions are common to relocation, renovation, and replacement, and the related costs are assumed to be equivalent for all cases.

Reuse of Foundation Only

If the existing foundation has sufficient capacity to support the new loads, then the foundation may be reused in its current condition. The existing capacity is often difficult to determine due to poor record keeping and potential, age-based deterioration, but it must be established prior to further intervention. If the foundation capacity is found to be inadequate, the foundation must either be enhanced or replaced. By reusing an existing foundation, the costs affiliated with foundation removal and reinstallation processes are negated. These costs depend on whether the foundation is a pile foundation, which is typically used for high-rise buildings and structures in clay, or a shallow foundation, which is often used for smaller structures and in dense sands and rock. As shallow foundations are relatively close to the ground surface, their removal and installation are straightforward compared to pile foundations, where the complexity and costs increase with depth for both installation and extraction.

Removal

The cost of pile foundation removal is directly tied to the total linear footage that must be removed. Excavation is an expensive option because of the large quantity of soil that needs to be removed. Extraction is a more economical pile removal method. For extraction, a vibratory hammer is attached to the pile head, and upward, axial vibrations are applied to pull the foundation element from the ground. Despite its potentially negative environmental impacts, this removal process is the most common, yet geometric limitations and material characteristics can impact the cost of extraction. As an example, a pile's tensile capacity may be insufficient to withstand the tensile forces applied during extraction, causing breakage, and leaving substantial portions of the pile in the ground. If pieces of the pile need to be removed, the pile's perimeter must be excavated to such a depth that the shaft capacity is less than the breaking strength of the pile, at which point the remaining length can be removed. On projects with a large number of piles, removal complications and debris generation can considerably increase both the cost and the schedule.

Installation

Similar to pile removal, the total linear footage directly impacts pile installation costs, however, unlike pile removal, a wide variety of installation methods exist. Material and installation method selection can be optimized to minimize cost, but irrespective of the selected method, there are common costs, including equipment mobilization, load testing, and pile cap construction.

Enhancement

If the existing foundation's capacity is inadequate, the foundation must be enhanced, either by adding foundation elements or improving the soil properties to increase capacity of in-situ elements. Jet grouted columns, helical piers, piles with transfer beams, and a variety of grouting techniques are some options (Shvets et al. 1996). Because of the varying degrees of uncertainty with enhancement methods, load tests are often required to verify that the foundation has been sufficiently upgraded. These tests can be expensive and, thus, may control the cost of the improvement efforts.

Quantified Costs

In the cost analysis example presented, the existing foundation consists of 56 piles (0.457 m diameter and a 15.24 m average length). Pile extraction costs can be considered similar to those affiliated with installation and is often driven by local labor practices and wages. Removal and disposal of the piles are estimated to cost $121,163 (Table 2). For a new foundation to have a capacity sufficient to support the proposed 50% load increase, a total of 84 piles (of the same dimensions as the existing piles) must be installed, costing $248,214. The total cost for foundation removal and reinstallation is $369,377. In order to reuse the existing foundation in the example, its capacity needs to be increased by 623 kN per interior pile group and 312 kN per corner pile group. Jet grouting was selected as the enhancement method, and based on the soil properties, a total of 66 jet grouted columns (1 m in diameter and 3.05 m average length) are needed to improve the foundation. Three load tests are assumed to be needed to test the enhancement, bringing the total cost for foundation enhancement to $141,672.

Reuse of Basement and Foundation

If the foundation can be reused to support the new loads, the basement must be adequate to transfer the new loads from the superstructure to the foundation. If the existing basement is sufficient to carry the new loads, immediate reuse is possible. If, however, the basement is inadequate for load transfer, the basement must either be enhanced or replaced. By reusing the basement, the costs of all sub-grade removal and reinstallation processes, as well as disposal and excavation support, can be averted.

Removal

The major expense associated with basement removal is the temporary excavation support. The close proximity of structures to urban site excavation puts adjacent buildings and utilities at risk of damage. To prevent the settlement and heave-induced damage, sufficient lateral support must be furnished with temporary excavation support to replace the lateral resistance previously provided by the basement. Sheet piles with tie back anchors, cross-lot bracing, or jet grouted columns are common support options (Fig. 8) and are selected by the soil profile, local practices, and site constraints. Excavation support needs to extend beyond the depth of the excavation to obtain static equilibrium and often extend 10 to 15 meters below the ground. To achieve a sufficiently stiff support system to minimize displacements, a large amount of support is needed and, typically, results in substantial costs. Once proper excavation support is achieved, the basement can be removed. Basements are not usually more than one or two stories below ground, and, consequently, only a small volume of soil around the perimeter needs to be excavated to gain access for basement removal. The minimal excavation costs make the removal of the basement's concrete slab and walls the controlling cost.

Installation

Basement reinstallation tends not to differ from new construction practices. After the existing basement has been removed, the new basement can be constructed largely within the footprint of the existing basement, and new excavation is only necessary to accommodate basement expansion. With minimal new excavation, the main basement installation related costs are the concrete and formwork for the new slab and walls.

Enhancement

If the existing basement provides insufficient load transfer, and basement space is not critical, then the existing basement can be modified to increase the load carrying capacity (Chapman et al. 2001) [Fig. 9]. The costs involved with basement modification are directly related to the volume of concrete installed to expand the load transfer area. By reusing the existing basement, excavation support is avoided as the basement continues to supply the necessary lateral support.

Quantified Costs

For the theoretical building, sheet piles were chosen to provide excavation support for basement removal. The cost for sheet pile wall installation (extending to a depth of 9.15 m and supporting the entire perimeter of the site) is $237,443 (Table 2). The cost for basement removal and disposal is $70,948. The new basement installation, assuming no new excavation, is estimated at $78,632, bringing the total replacement costs to $387,023. To reuse the basement, enhancement requires doubling the width of the basement wall thickness at a cost of $26,546.

Reuse of AGS, Basement, and Foundation

The renovation of the AGS allows for complete building reuse. This combination offers the greatest potential cost savings by precluding all removal and reinstallation costs, especially, the tremendous cost of reconstruction.

Removal

The demolition costs associated with the AGS are relatively low and vary based on the AGS’s structural system and cladding materials and the selected demolition method. The main cost related to AGS removal is the disposal of the demolition debris, which varies depending on local disposal fees.

Installation

The major expense related to building replacement is the AGS reconstruction. The cost for reconstruction can be assumed to be equivalent to that of new construction, as the entirety of the building is new. For high-rise buildings with more than 10 floors, the average new construction cost is $1,152 per square meter of floor space (Means 2002).

Enhancement

AGS reuse provides the greatest economic benefit, because of the high cost of reconstruction. Typically, the AGS must be renovated to meet the new programmatic needs. The costs of the necessary renovation are specific to each project, and structural modifications can cause dramatic variations in the total renovation cost.

Quantified Costs

A 50% increase in the working space is required for the theoretical building. The confined site conditions dictate that the new space be acquired vertically, requiring the 10 story building to expand to 15 stories. Replacement requires the AGS to be demolished and reconstructed. The demolition of the existing 10 stories costs approximately $180,724 (Table 2), and the cost for the construction of a new 2,789 square meter, 15 story building is $4,718,709. The total replacement cost for the AGS is $4,899,433. For renovation, if the basement and foundation are enhanced to adequately support the new load, the new 5 stories must be added above the existing 10 stories to meet the additional working space requirements. With this additional load, sufficient alterations to the superstructure must be made to support the new stories and the increased lateral loads. The new construction of 5 stories is approximately

$1,572,903, and an increase in the structural capacity is estimated at $205,800, for a total AGS renovation cost of $1,778,704.

Quantified Cost Summary

A cost breakdown of the total replacement of the theoretical building can be seen in Figure 10, with the cost related to each building component reuse combination in Table 4. The most cost-effective solution is also the most environmentally friendly. If all of the building is reused, then 65% of the total replacement costs can be saved. If the foundation and basement are reused, approximately 10% can be saved. If only the foundation is reused, a 4% savings can be realized, which for a 5.5 million dollar building, represents $220,000 in direct savings.

CASE HISTORIES

As a theoretical analysis can never fully reflect the specific challenges and details of a particular project, this section presents two actual case histories. What follows is a comparison of the large-scale renovation of two similar, early twentieth century, load-bearing brick buildings in New York City (Table 5). Both Building A and Building B (Fig. 11) were extended from four stories to five and a half (Fig. 12), had existing loads of 145 kN per linear meter, new loads of approximately 163 kN per linear meter, 287 kPa soil bearing capacity, and party walls on each side into which the floor beams were fitted. The foundation of both buildings consisted of cemented rubble stone approximately three-quarters of a meter wide, representing three times the triple-wythe brick walls. Both building renovations included extensive work related to the elevators and elevator pits and required some utility relocation. Neither needed supplementary lateral reinforcement nor substantial structural changes.

The additional story and a half for Building A increased the original square footage of the original 30.5 meter x 6.1 meter floor plan by 12%. The deteriorating front facade of the upper four floors was replaced (the first floor facade was previously renovated), but all the original flooring was left in place. A new basement slab was installed, the existing shallow underpinning from previous construction was partially restored, and additional shallow underpinning was constructed to support a new elevator pit. In contrast, the square footage of Building B (21.3 meter x 6.1 meter floor plan) increased only 3%. No alterations were permitted to the façade of Building B due to its location in a historically designated neighborhood (Fig. 11), however, the entire back facade was removed and replaced with a glass wall. All of Building B's flooring systems were replaced, and the basement was extended into the back of the lot. Only beneath the new basement extension was foundation work installed, which was restricted to new footings.

Cost Analysis

While each building was similar in initial configuration and shared a similar scope of renovation, the actual renovation cost of Building A was approximately 20% less than that of Building B (Table 6). A major expense for Building B came about from the \$150,000 extension of the foundation and basement and a \$190,000 rear glass façade, as compared to the \$43,000 underpinning restoration and the \$10,000 replacement masonry façade for Building A. With these distinctions taken into account, the difference in actual renovation cost reduces to 12%. Based on \$350,000 demolition costs, new construction costs of \$2690/m^2 and the reuse of the existing foundations, the estimated partial replacement (replacing the AGS and basement) of Building A would be \$2,616,000 and of Building B would be \$2,080,750. Thus, the estimated partial replacement cost of Building A would be 10% higher than the actual renovation costs (Table 6). Conversely, the AGS replacement for Building B was 70% lower than renovation. If new shallow foundations (approximately $350,000) were required for both buildings, the estimated total replacement cost for Building A would become $2,966,000 and for Building B $2,430,750. Consequently, the estimated total replacement of Building A is 24% higher than the actual renovation costs and the actual renovation cost of Building B is 23% greater than estimated total replacement; for Building B, total replacement of the AGS was not an option because of its location within a protected historic community.)

In comparing the theoretical analysis and the two case histories by cost per square meter, it can be seen that the driving factor in the potential cost savings through renovation is the building's floor space (Table 6). The theoretical building, at approximately 4,090 square meters, offers the highest potential for savings through reuse, going from $\$1,377/m^2$ for total replacement to $\$473/m^2$ for reuse. Building A, at 842 m^2, offers the next highest savings going from $\$3,518/m^2$ for total replacement to $\$2,829/m^2$ for the actual renovation cost. Finally, Building B, the smallest of the projects at 577 m^2, is actually more expensive to renovate than to replace, going from $\$4,207/m^2$ for total replacement to $\$5,207/m^2$ for actual renovation. This high renovation cost was driven by the total gut renovation of Building B, which included complete floor and stair well replacement. While building floor space can determine the economy of renovation, another driving factor that can affect renovation costs is the foundation type. Typically, pile foundations are more expensive than shallow footings, and for smaller projects the replacement of pile foundations can constitute a large percentage of the replacement costs. For the large theoretical building previously described, the pile foundation replacement contributes only a small percentage (6%) to the overall cost.

CONCLUSION

When the design life of any building has expired, it must be either renovated or replaced. Often times, sustainable solutions are overlooked in favor of traditional options that were once definitively more economical. With advancing technologies, alternative solutions are increasingly becoming economically competitive. Total or partial building reuse is a solution that contributes to both direct financial gain and environmental sustainability. As each project is distinct, some are more amenable for partial reuse. Within this paper, one of two case histories demonstrated that renovation can be an economical, as well as an environmentally friendly solution, with a tendency for greater savings for larger projects. Additional benefits beyond direct cost savings include an abbreviated construction schedule, reduced liability, decreased impacts to surrounding facilities, as well as many enhanced environmental sustainability. The 10 step sustainability assessment procedure presented based on nearly two decades of professional experience by the authors should be implemented to most effectively determine the reusability of a building and to realize the affiliated benefits. When applied to a theoretical building with deep foundations, savings from 4-65% were possible depending upon how much of the existing structure is retained.

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LIST OF TABLES

FIGURE CAPTIONS:

Figure 1. Summary of C&D debris generation (data from Franklin Associates, 1998)

Figure 2. Benefits of building component reuse

Figure 3. Building components

Figure 4. Soil heave, settlement, and lateral expansion caused by basement removal

Figure 5. Flow chart for sustainability assessment

Figure 6. Column support vs. transfer girder

Figure 7. Combinations of building reuse

Figure 8. Various excavation support techniques

Figure 9. Basement enhancement through increased bearing area

Figure 10. Cost breakdown for complete replacement of an existing building

Figure 11. Front façade of Building B (Courtesy of Howard B. Spivak Architects)

Figure 12. Renovations for Building A and Building B

Table 1. Existing Building Properties

	AGS	Basement	Foundation
pacity of 70kPa + 7kPa/m	•10 story steel frame (each floor 3.66m x 12.8 m x 21.34m) •Floor space 2,731m^2 •Volume 327,782m^3	•Depth 3.66m •Slab thickness 0.152m •Wall thickness 0.203m •Floor space 273.1m^2 •Volume 3,277m^3	•Concrete piles (0.457m diameter x 15. •4 pile groups of 9 piles •4 pile groups of 5 piles

Table 2. Cost analysis for removal and reinstallation of building components

Process	$/unit	Unit	Qty	Cost[a]
Costs related to demolition of the AGS				
Mobilize demolition equipment	$8,525.00	each	1	$8,525
Demolish the AGS[b]	$8.83	m^3	9,990	$88,200
Dispose of the AGS debris	$11.58	m^3	2,842	$32,899
Dump fee for waste	$0.02	kg	3,218,507	$51,100
			SUBTOTAL	$180,724
Costs related to removal of basement				
Mobilize excavation equipment	$325.00	each	2	$650
Structurally excavate	$11.77	m^3	245	$2,880
Remove the slab	$55.43	m^2	273	$15,141
Remove the walls	$134.55	m^2	250	$33,600
Dispose of basement debris	$16.74	m^3	92	$1,547
Dump fee for waste	$0.02	kg	1,078,996	$17,130
			SUBTOTAL	$70,948
Costs related to foundation removal				
Remove the piles[c]	$111.55	m	853	$95,199
Dispose of foundation debris	$16.74	m^3	140	$2,345
Dump fee for waste	$0.02	kg	1,635,449	$25,964
			SUBTOTAL	$121,163
Costs related to temporary support				
Support the excavation	$0.39	kg	605,171	$237,443
			SUBTOTAL	$237,443
Costs related to foundation installation				
Mobilize pile driving equipment	$19,000.00	each	1	$19,000
Drive the piles	$111.55	m	1,280	$142,798
Load test the piles	$25,700.00	each	3	$77,100
Install the pile caps	$221.04	m^3	42	$9,316
			SUBTOTAL	$248,214
Costs related to basement installation				
Construct the slab	$157.15	m^2	273	$42,924
Construct the walls	$351.84	m^3	101	$35,708
			SUBTOTAL	$78,632
Costs related to AGS construction				
Construct the AGS	$1,151.74	m^2	4,870	$4,718,709
			SUBTOTAL	$4,718,709
			TOTAL	**$5,655,834**

[a] All unit prices are from Means (2002) and include contractors' overheads and profits

[b] Per cubic meter of building standing

[c] Personal communication with Dr. Michael Wysocky of Thatcher Engineering Corporation, European reports suggest 2-5 times installation costs (Chow et al. 2002)

Table 3. Cost analysis for building component modification

Process	$/unit	Unit	Qty	Cost[a]
Costs related to foundation enhancement				
Mobilize grouting equipment[b]	$15,000.00	each	1	$15,000
Jet grouting[b]	$313.91	m^3	158	$49,572
Load test piles	$25,700.00	each	3	$77,100
			SUBTOTAL	$141,672
Costs related to basement improvement				
Increase basement wall thickness	$523.18	m^3	51	$26,546
			SUBTOTAL	$26,546
Costs related to AGS renovation[c]				
Enhance structural capacity	$75.35	m^2	2,731	$205,800
New construction	$1,151.74	m^2	1,366	$1,572,903
			SUBTOTAL	$1,778,704
			TOTAL	**$1,946,922**

[a] All unit prices are from Means (2002) and include contractors' overheads and profits

[b] Unit price based on multiple combined processes from Means (2002)

[c] Not including upgrades for current building code service requirements

Table 4. Total cost per building reuse combination

Reuse combination	**Foundation, basement, and AGS**	**Foundation and basement**	**Foundation only**	**No reuse**
Foundation removal	-	-	-	$121,163
Foundation installation	-	-	-	$248,214
Foundation enhancement	$141,672	$141,672	$141,672	-
Basement removal	-	-	$308,391	$308,391
Basement installation	-	-	$78,632	$78,632
Basement improvement	$26,546	$26,546	-	-
AGS removal	-	$180,724	$180,724	$180,724
AGS installation	-	$4,718,709	$4,718,709	$4,718,709
AGS enhancement	$1,778,704	-	-	-
TOTAL	**$1,946,922**	**$5,067,651**	**$5,428,128**	**$5,655,833**

Table 5. Comparison of two modified buildings

BUILDING A	BUILDING B
AGS	
Original floor area = 748 m^2	Original floor area = 555 m^2
New floor area = 843 m^2	New floor area = 577 m^2
4 existing floors	4 existing floors
2 party walls	2 party walls
New loading = 163 kN per linear meter	New loading = 163 kN per linear meter
Floor beams remained	Floor beams removed and replaced
No lateral reinforcement necessary	No lateral reinforcement necessary
Some utility relocation	Some utility relocation
New elevator and elevator pit	Entire 5 story rear façade removal
Upper 4 story front façade replacement	New rear glass façade
Roof straightening	Partial 5 story rear masonry wall extension
Basement	
Full basement	Full basement
Foundation	
287 kPa bearing capacity	287 bearing capacity
Cemented rubble stone footings	Cemented rubble stone footings
Wall width 2.5 times the 3 wythe wall	Wall width 2.5 times the 3 wythe wall
Portion of the existing underpinning restored	Existing underpinning extended for basement
Small additional underpinning for elevator	
New basement slab	

Table 6. Cost comparison of sustainable reuse for Buildings A and B

Description	Building A		Building B[a]	
	Total Cost	Cost/m^2	Total Cost	Cost/m^2
Actual renovation costs	$2,383,724	$2,829	$3,000,000	$5,203
Partial replacement (replace AGS & basement)[b]	$2,616,000	$3,105	$2,080,750	$3,609
Total replacement (replace all components)[b]	$2,966,000	$3,520	$2,430,750	$4,216

[a] Building B costs include $180,000 difference between the glass wall and masonry wall

[b] Estimated costs

Figure 1.

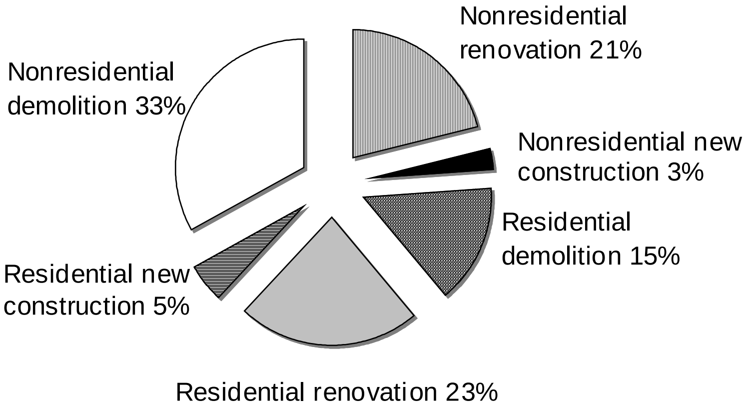

Nonresidential renovation 21%
Nonresidential new construction 3%
Residential demolition 15%
Residential renovation 23%
Residential new construction 5%
Nonresidential demolition 33%

Figure 2.

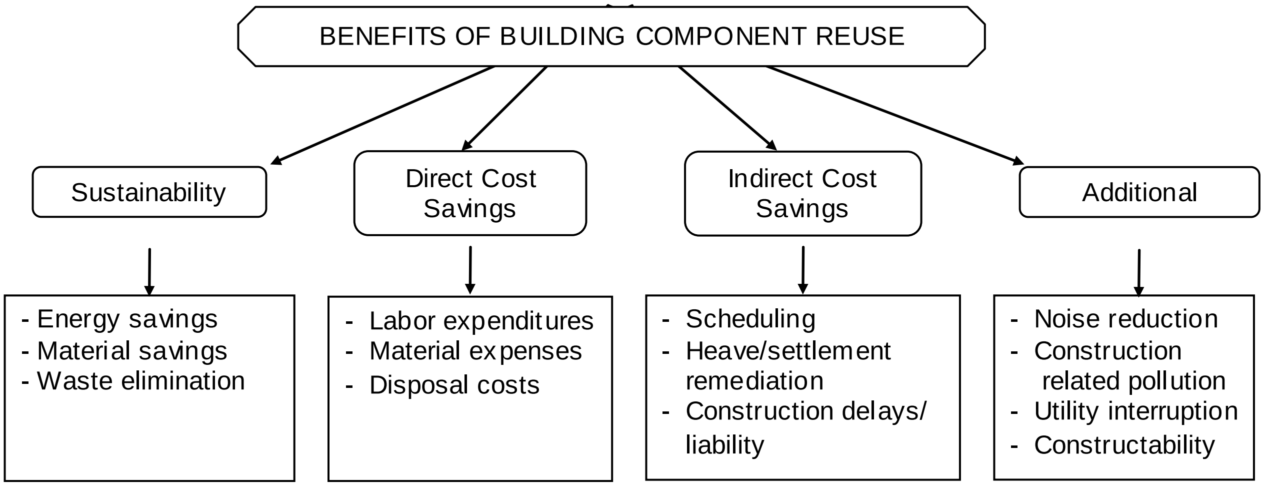

BENEFITS OF BUILDING COMPONENT REUSE
Sustainability
Direct Cost Savings
Indirect Cost Savings
Additional
- Energy savings
- Material savings
- Waste elimination
- Labor expenditures
- Material expenses
- Disposal costs
- Scheduling
- Heave/settlement remediation
- Construction delays/ liability
- Noise reduction
- Construction related pollution
- Utility interruption
- Constructability

Figure 3.

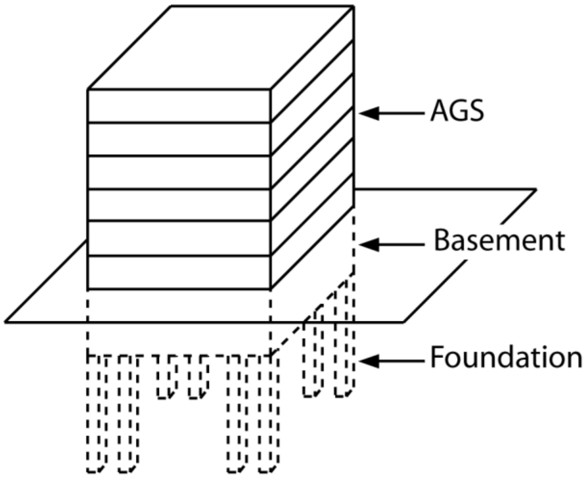
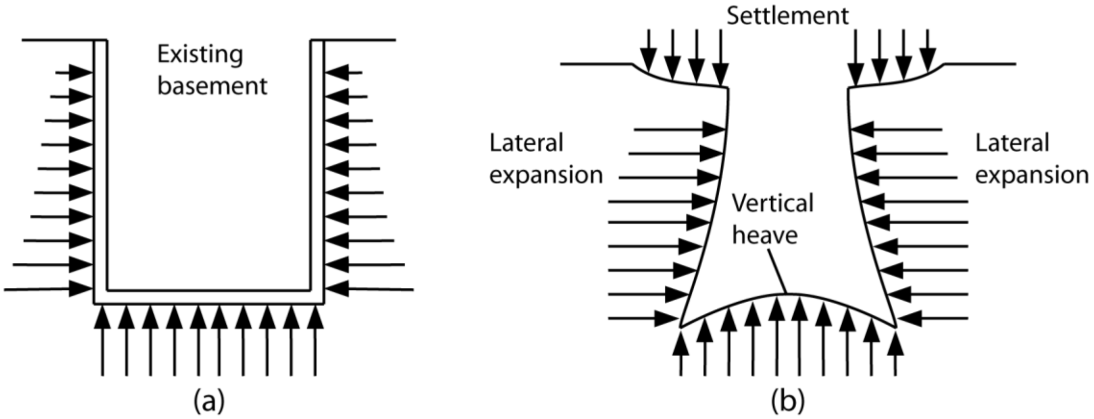


Figure 4.



Existing basement providing earth support

Removed basement resulting in soil movement

Fig. 5

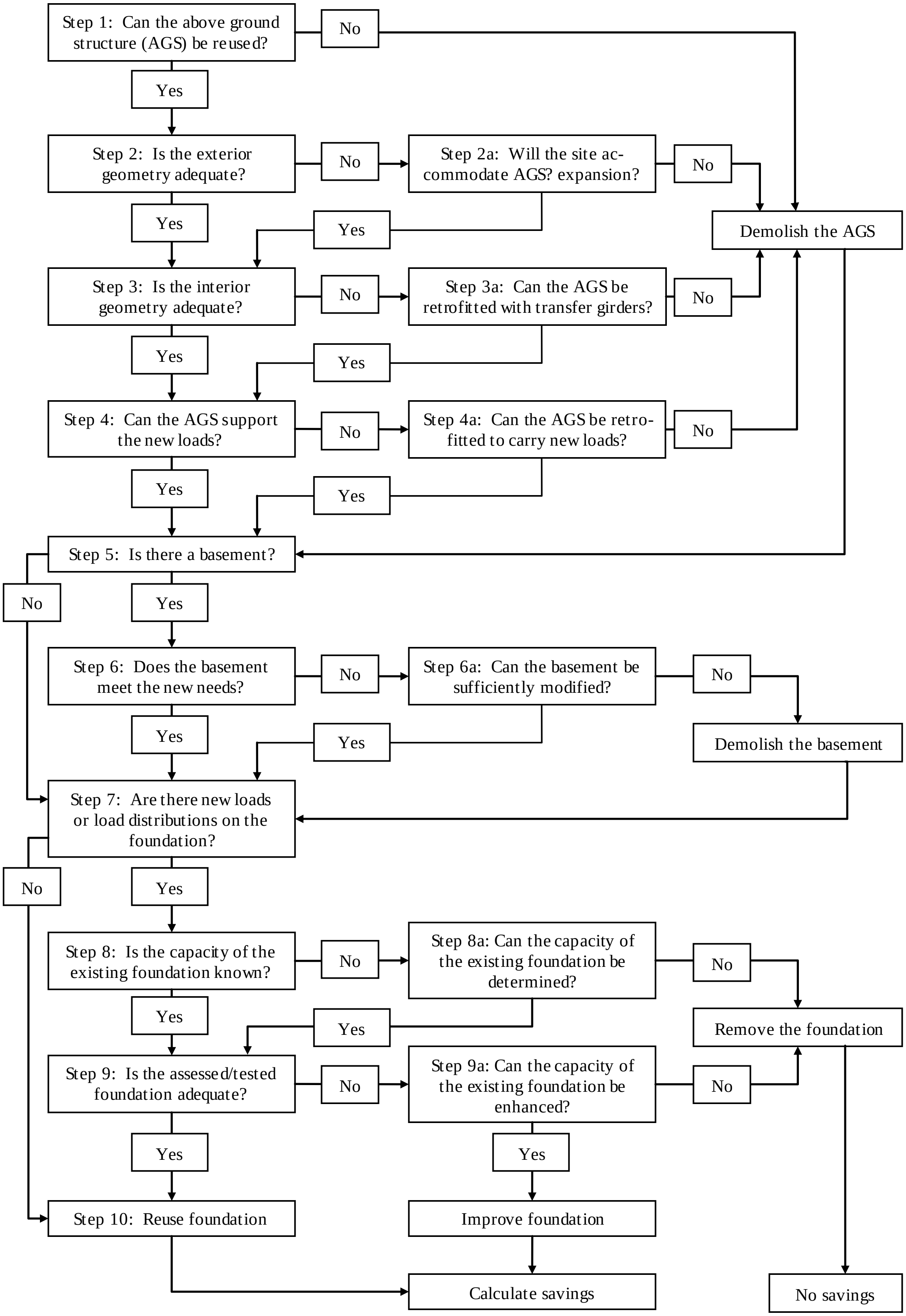
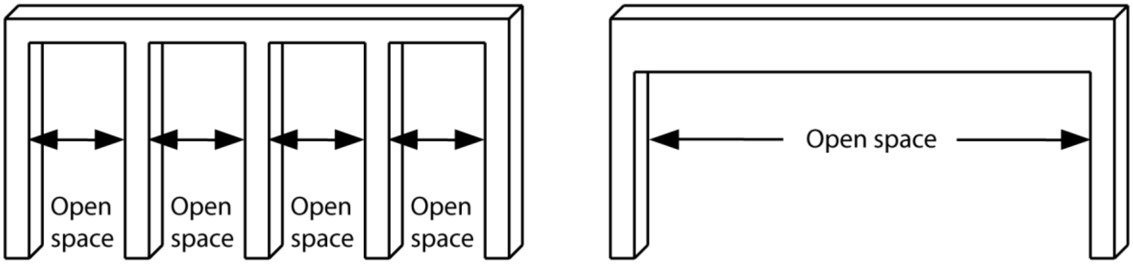

Step 1: Can the above ground structure (AGS) be reused?
No
Yes
Step 2: Is the exterior geometry adequate?
No
Step 2a: Will the site accommodate AGS? expansion?
No
Demolish the AGS
Yes
Yes
Step 3: Is the interior geometry adequate?
No
Step 3a: Can the AGS be retrofitted with transfer girders?
No
Yes
Yes
Step 4: Can the AGS support the new loads?
No
Step 4a: Can the AGS be retrofitted to carry new loads?
No
Yes
Yes
Step 5: Is there a basement?
No
Yes
Step 6: Does the basement meet the new needs?
No
Step 6a: Can the basement be sufficiently modified?
No
Demolish the basement
Yes
Yes
Step 7: Are there new loads or load distributions on the foundation?
No
Yes
Step 8: Is the capacity of the existing foundation known?
No
Step 8a: Can the capacity of the existing foundation be determined?
No
Remove the foundation
Yes
Yes
Step 9: Is the assessed/tested foundation adequate?
No
Step 9a: Can the capacity of the existing foundation be enhanced?
No
Yes
Yes
Step 10: Reuse foundation
Improve foundation
Calculate savings
No savings

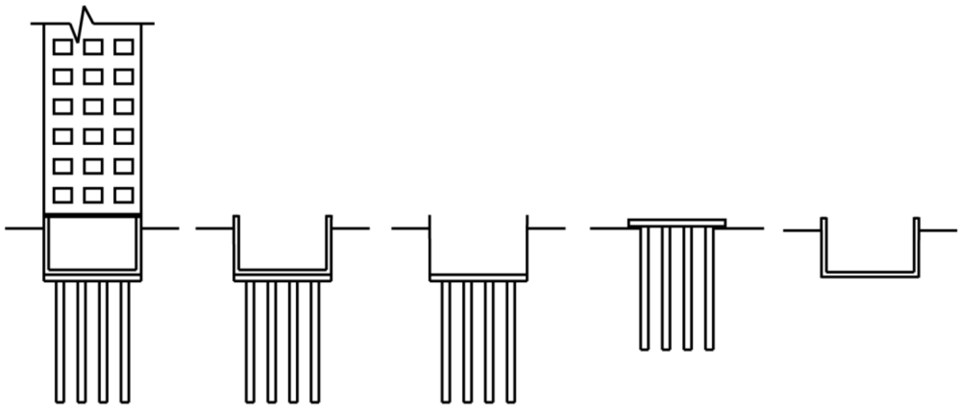
Figure 6.



Column supported

Transfer girder

Figure 7.



(a)
Reuse AGS,
basement and
foundation

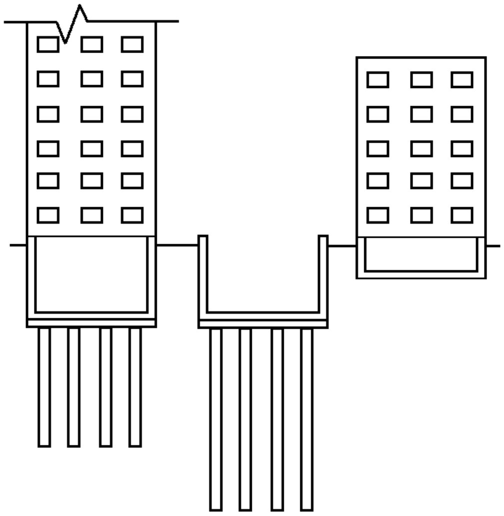
(b)
Remove AGS,
reuse basement
and foundation

(c)
Remove AGS,
and basement,
reuse foundation

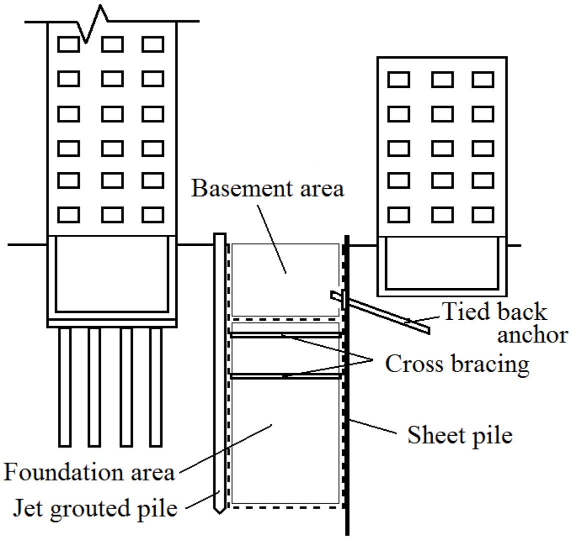
(d)
Remove AGS,
no basement
reuse foundation

(e)
Remove AGS,
no foundation
reuse basement

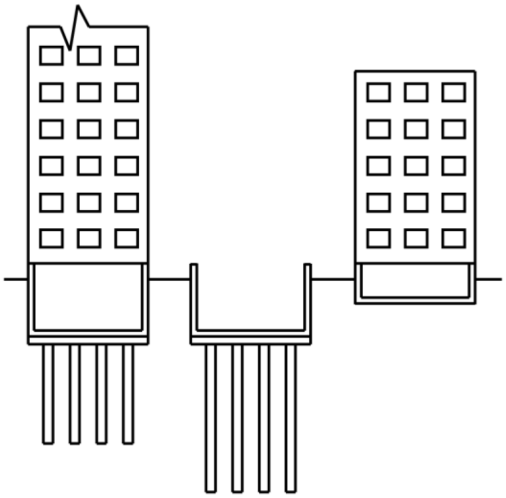
Figure 8.



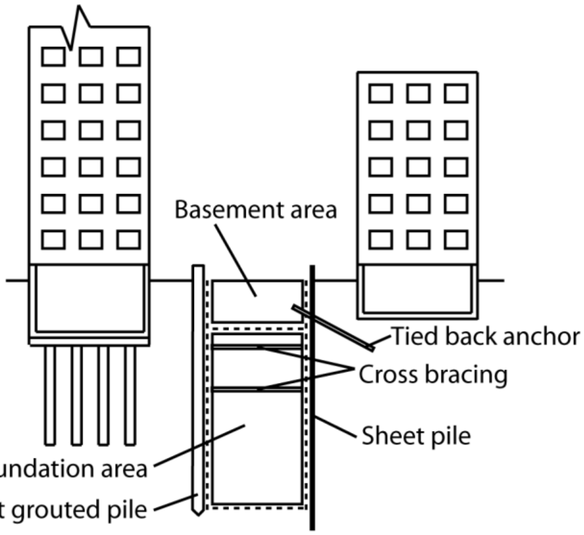
Adjacent structures to an existing basement and foundation



Temporary excavation support in place of removed basement and foundation



Adjacent structures to an existing basement and foundation



Temporary excavation support in place of removed basement and foundation

Figure 9.

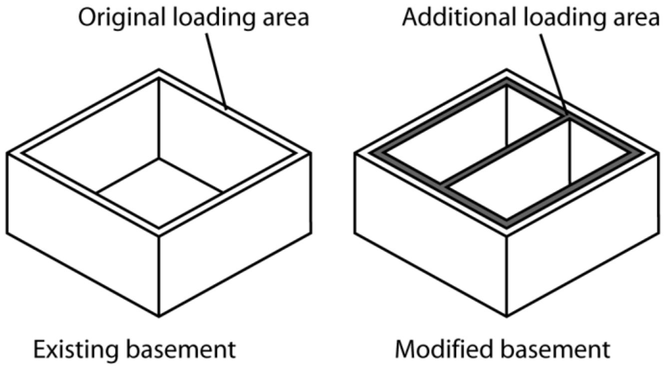

Original loading area
Additional loading area
Existing basement
Modified basement

Figure 10.

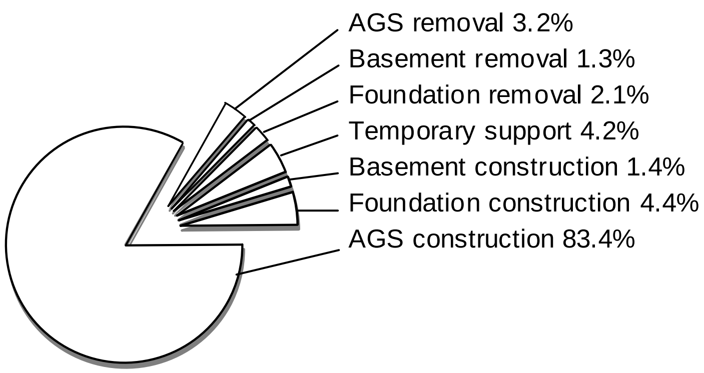
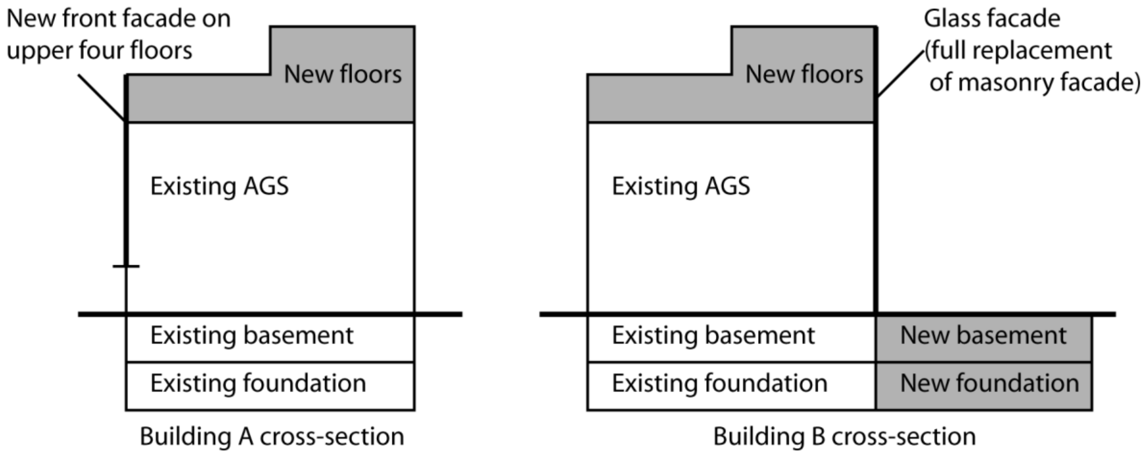

AGS removal 3.2%
Basement removal 1.3%
Foundation removal 2.1%
Temporary support 4.2%
Basement construction 1.4%
Foundation construction 4.4%
AGS construction 83.4%

Figure 11.

Figure 12.


New front facade on upper four floors
New floors
Existing AGS
Existing basement
Existing foundation
Building A cross-section
New floors
Glass facade (full replacement of masonry facade)
Existing AGS
Existing basement
New basement
Existing foundation
New foundation
Building B cross-section

REFERENCES

Agyeman, J., and Evans, T. (2003). "Toward just sustainability in urban communities: Building equity rights with sustainable solutions." *Annals Am. Acad. Pol. and Soc. Sci.*, 590, 35-53.

ASCE (2003). *ASCE Standard: Minimum Design Loads for Buildings and Other Structures.* ASCE, Reston, VA.

Baetz, B.W., and Korol, R.M. (1995). "Evaluating technical alternatives on basis of sustainability." *J. Prof. Issues Eng. Edu. and Pract.* 121(2), 102-107.

Brugmann, J. (1992). *Managing human ecosystems: Principles for ecological municipal management,* Int'l Council for Local Environmental Initiatives, Toronto, Canada.

Chapman, T.J.P., March, B., and Foster, A. (2001). "Foundations for the future." *Proc Inst. Civil Eng. Civil Engineering,* 144 (February), 36-41,

Chapman, T.J.P., Chow, F.C., and Skinner, H. (2002). "Building on old foundations – sustainable construction for urban regeneration." *CEWorld Conference,* ASCE on-line conference.

Chapman, T.J.P., Butcher, A. and Fernie, R. (2003). "A generalised strategy for reuse of old foundations." *Proc., XIII European Conference on Soil Mechanics and Geotechnical Engineering,* ISSMGE Prague, Czech Republic, Vol. 1, 613-618.

Chow, F.C., Chapman, T.J.P., and St John, H.D. (2002). "Reuse of existing foundations: planning for the future." *Proc. 2nd Int'l Conf. Soil Structure Interaction in Urban Civil Engineering,* Swiss Federal Institute of Technology Zurich, Zurich, Switzerland. 171-176.

Chung, S.S., and Lo, C.W.H. (2003). "Evaluating sustainability in waste management: The case of construction and demolition, chemical and clinical wastes in Hong Kong." *Resources Conservation and Recycling,* 37(2), 119-145.

Davies, A.R. (2005). "Incineration politics and the geographies of waste governance: A burning issue for Ireland?" *Environment and Planning C-Government and Policy,* 23(3), 375-397.

DiNino, T., and Baetz, B.W. (1996). "Environmental linkages between urban form and municipal solid waste management infrastructure" *J. Urban Planning and Development*, 122(3). 83-100.

DLRCOCO (2005). "Over the past 10 years the amount of waste produced in Ireland." http://www.dlrcoco.ie/env/education/LEAP/wasteheirarchy.htm (April 7, 2006).

Forfas, (2005). "Key waste management issues in Ireland." http://www.forfas.ie/publications/waste_management_01/waste-man-infra.htm#asterisk1 (April 7, 2006).

Franklin Associates (1998). "Characterization of Building-Related Construction and Demolition Debris in the United States." *Report No EPA530-R-98-010.* Prairie Village, KS.

Fung, M., and Kennedy, C.A. (2005). "An integrated macroeconomic model for assessing urban sustainability." *Env and Planning B-Planning and Design*, 32(5), 639-656.

Georges, N.M. (2006). "Solid waste as an indicator of sustainable development in Tortola, British Virgin Islands." *Sustainable Development,* 14(2), 126-138.

Horwood, R. (2005). "The pathway to sustainable resource management." *Process Safety and Env. Protection,* 83(B6), 504-508.

HUD (2003). Department of Housing and Urban Development, "A report on the feasibility of deconstruction: An investigation of deconstruction activities in four cities." Washington D.C.

Katzenbach, R., Weidle, A., and Ramm, H. (2003). "Geotechnical basics in modeling of the soil-structure-interaction due to the sustainable re-use of historical foundations and structures." *Reconstruction of Historical Cities and Geotechnical Engineering*, V.A. Ilichev, and V.M. Ulitsky, eds., ASV Publishers, Saint Petersburg, Moscow., Vol. 1, 85-94

Maydl, P. (2004). "Sustainable engineering: State-of-the-art and prospects." *Structural Engineering International,* 14 (1), 176-180.

McDougall, F.R., and Hruska, J.P. (2000). "Report: The use of life cycle inventory tools to support an integrated approach to solid waste management." *Waste Management and Research,* 18(6), 590-594.

Means, R.S. (2002). *Building Construction Cost Data, 61st Annual Edition, 2003,* R.S. Means Co. Inc., Kingston, MA.

Mitchell, J.K. (1993). *Fundamentals of Soil Behavior, 2nd Ed.*, John Wiley and Sons Inc., New York, NY.

Montana State University (MSU) Extension Service (2003). "Building-Related C&D Waste Characteristics" http://peakstoprairies.org/p2bande/construction/C&DWaste/ (April 7, 2006).

Ontario Round Table on Environment and Economy (ORTEE) (1992). *Structuring for sustainability*, Toronto, Canada.

Re-Use of Foundations of Urban Sites (RUFUS), (2006). *CIRIA guide foundation reuse,* February draft.

Shvets, V.B., Feklin, V.I., and Ginzburg, L.K. (1996). *Reinforcement and reconstruction of foundations*, A.A. Balkema, Brookfield, VT.