Decision-making analysis for Pittsburgh's deconstruction pilot using AHP and GIS

COLLECTION: UNDERSTANDING DEMOLITION

RESEARCH

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ABSTRACT

Deconstruction—the systematic disassembly of reusable and recyclable components and materials—is being actively promoted in a growing number of US cities to reduce the enormous amount of construction demolition waste sent to landfill. Research has highlighted local and regionally specific criteria influencing the decision on deconstruction, but it remains unclear how to decide which city-owned condemned properties in Pittsburgh should be considered for the new deconstruction pilot program. Therefore, this study establishes a prioritization model to distinguish the relative importance of factors using the analytic hierarchy process (AHP). According to local experts, the four most impactful criteria are the environmental impact, economic impact, resources and type of properties. Fourteen factors within these criteria are selected for detailed comparison. The relative importance of these factors is then used to weight spatial map overlays to classify condemned properties into four deconstruction value categories. As a result, this study offers a new methodology to evaluate potential deconstruction projects by weighting the criteria most valued by decision-makers in Pittsburgh, which could be altered and expanded to fit the values of other cities.

PRACTICE RELEVANCE

A robust decision-making process involving experts, local stakeholders and city officials is created for the selection of buildings to be deconstructed rather than demolished. The decision process is based on a comprehensive analysis of environmental, economic, resource and building-type criteria. A clear process is also established for the identification of the advantages and limitations of the approach. This provides a prioritization of potential deconstruction locations based on experts' subjective judgements and an objective dataset, concluding that the highest value of deconstruction should be first considered by decision-makers. This pilot project provides a proof of concept of the group decision-making process. City-owned condemned buildings in Pittsburgh were divided into four categories with different deconstruction values by the combination of AHP and geographic information systems (GIS) analysis. The relationship and consistency between the condemned properties in each category and the deconstruction value are considered in detail.

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1. INTRODUCTION

Research about reuse and recycling in construction has mainly focused on design and construction, and rarely mentions construction and demolition (C&D) waste. However, scarce resources (wood, metal, natural gas) and components (piping, heating systems) are wasted during demolition and should be recovered through deconstruction (Schultmann & Sunke 2007). In addition to the waste, Schultmann and Sunke (2007) also concluded that the large amount of emissions and hazardous substances released to the environment during demolition is contrary to the aim of sustainability. Unlike conventional methods of demolition and landfilling, deconstruction decreases environmental impacts by significantly reducing disposals in landfills by reusing up to 85% of construction materials (Tatiya *et al.* 2018). To reduce waste and enhance sustainability in construction, decision-makers from different US cities have implemented several regulations and programs to increase the use of deconstruction rather than demolition. These cities focus on deconstruction because it preserves the value of building materials and contributes to sustainable development (US EPA 2018).

As described below, these city-scaled deconstruction efforts discuss various factors affecting deconstruction and provide a basis for the decision-making of local governments and other stakeholders. Cases from Baltimore (Maryland), Seattle (Washington) and San Antonio (Texas) provide valuable insight into how these factors impact the decision-making processes.

The City of Baltimore is explicitly concerned about the environmental impacts of demolition waste and the opportunities for economic development associated with deconstruction (Hines 2021). The purpose of Baltimore's deconstruction is to stimulate the recovery of the urban wood-processing industry and enrich community spaces occupied by vacant buildings. The factors on which they focused were climate change and the diseases it brings, labor costs, green materials, and transportation costs. In addition to these factors, decision-makers in Baltimore found that spatial differences affect the spread of deconstructing projects throughout the city with regional ecological and social needs. Therefore, identifying potential vacant buildings and areas that would benefit the most from deconstructing buildings is Baltimore's top priority even if the buildings are not slated to be demolished.

The City of Seattle is primarily concerned with the C&D waste and biosafety disposal of hazardous asbestos and lead (City of Seattle 2021). These concerns make recycling and debris drop-off facilities, and groundwater resources important for Seattle's deconstruction. It is necessary to transport the debris of the project to the above-mentioned facilities to apply for the deconstruction of a residential project in Seattle. Another important indicator for applying for deconstruction is the percentage of recycling materials, which is one of the determinants of whether the project can be approved. Approved buildings must be associated with structural removal but not necessarily slated for demolition. Therefore, Seattle's deconstruction projects are significantly affected by materials and various resources.

The City of San Antonio's deconstruction activities are a combination of environmental, economic, and social factors (City of San Antonio 2017). Deconstruction is environmentally affected by toxic dust, waste to landfill, and consumption of materials. It is economically affected by sales of products and socially affected by contractor qualification and locally reclaimed materials used in the preservation of historic structures. Considering so many factors, San Antonio believes that its deconstruction project can solve important environmental issues and achieve sustainable goals.

To summarize, the cases of the three cities emerged from their own needs and what they think are the most important factors for deconstruction. Figure 1 shows the different considerations of the three cities. The City of Seattle is mostly concerned about the environment and less about the economy, which is the opposite of the City of Baltimore. The City of San Antonio explicitly addressed all three criteria sustainability areas (environment, economy, and society). However, these factors are locally and regionally specific, making it difficult to copy the experience of one city to another. The commonality of cities that have successfully practiced deconstruction is that they have clearly identified the most important factors affecting deconstruction and set reasonable policies.

As a typical city in the Rust Belt of the US, Pittsburgh (Pennsylvania) experienced a rapid reduction of jobs and population after the decline of its steel-based manufacturing base, which led to a high percentage of vacant and abandoned properties (Ghosh *et al.* 2019). To remove blight in a way that would provide jobs and reuse existing construction materials, the mayor of Pittsburgh issued an executive order on 20 April 2021 to develop a unified city-led deconstruction policy and establish a pilot program on city-owned condemned properties (City of Pittsburgh 2021b). Therefore, it is necessary to find the most important factors affecting the deconstruction in Pittsburgh and use these factors to find feasible deconstruction projects.

As determined by the City of Pittsburgh's Department of Permits, Licenses, and Inspections (PLI), condemned properties are vacant buildings with structural hazards that are unfit for human occupancy (City of Pittsburgh 2021a). Approximately 20% of these properties have become city-owned due to outstanding taxes. From the city's perspective, these buildings are a public danger and liability that should be removed as soon as possible because city funds are not sufficient to bring them up to code in a timely manner. Therefore, city-owned condemned properties were targeted for Pittsburgh's deconstruction pilot program.

This paper obtained those factors through case studies and literature reviews and used the analytic hierarchy process (AHP) to determine their relative importance. These results were then used to generate spatial map layers and used in decision-making for project selection. This paper clarified the influencing factors of deconstruction, providing a new decision-making process for decision-makers in Pittsburgh.

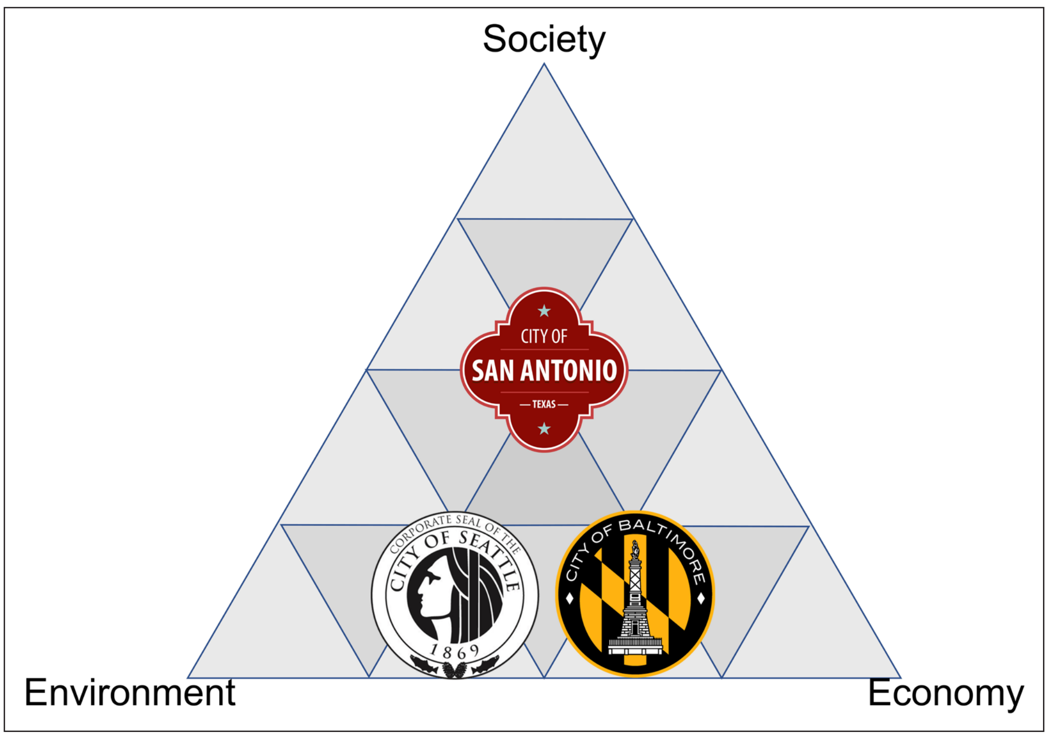

Figure 1: Guiding criteria for deconstruction efforts in three US cities.

2. LITERATURE REVIEW

Past research has provided a significantly detailed analysis of the factors that affect, and can be affected by, deconstruction. These studies mainly focus on the environment, resources, economy, and building type.

2.1 ENVIRONMENT CRITERIA

This section briefly considers the contribution of deconstruction to the environment and green building. Reusing building materials instead of landfilling can produce considerable economic and environmental benefits. According to Ding *et al.* (2016), deconstruction can reduce energy consumption and transportation to landfills by at least 50% according to an agent-based model, as well as reduced emissions of nitrous oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), and particulate matter (PM) by 50%. Considering the environmental impact from the construction life cycle, Assefa & Ambler (2017) concluded that seven categories impacted by deconstruction and demolition. Through life cycle analysis (LCA) using EcoCalculator, deconstruction and demolition have a profound impact (reductions between 20% and 41%) on the following six categories assessing the environmental impact: eutrophication potential, smog potential, human health criteria, acidification potential, global warming potential (GWP), and fossil fuel consumption.

In terms of green recycling and sustainable development, the concept of 'cradle to cradle' material recycling developed by McDonough & Braungart (2002) further clarifies the beneficial effects of destructed materials on construction activities. Even though deconstruction will cost more and take more time compared with demolition, it is much more environmentally friendly. Taking steel as an example, environmental pollution will be reduced by 96% through deconstruction and recycling compared with the use of new steel (Cheshire 2019). This study combines the environmental impact of gas, smog, and PM emissions into an *air pollution factor*; the pollutants associated with human health into *health factor*; and impacts associated with building carbon emissions and GWP into the *fuel consumption facto*r.

2.2 RESOURCE CRITERIA

The relationship between deconstruction and different resources is summarized as follows. Past research has found that resource consumption and energy consumption can be greatly reduced by recycling and reusing materials. Deconstructing building materials can take this further by enhancing different use of materials (Assefa & Ambler 2017). By comparing the meaning of the concepts of 'recycling', 'reuse', and 'deconstruction', Schultmann and Sunke (2007) considered the similarities between the construction industry and the manufacturing industry. When considering the building deconstruction plan, they focus on the repair, renovation, dismantling, and reuse of materials. More specifically, the number of renewable and recyclable materials obtained from a deconstruction project is a key determinant of the establishment of a deconstruction project (Schultmann & Sunke 2007).

For example, concrete and wood are two kinds of significant materials that can be recycled from deconstruction. The US EPA's Office of Resource Conservation and Recovery paid more attention to different material types while considering secondary uses and concluded that the greatest quantity of construction-related debris is from concrete (US EPA 2018). However, Höglmeier *et al.* (2017) conducted a similar case study of Germany and found that wood is the most effective material for deconstruction. When making a deconstruction decision, in addition to whether it is recyclable, another equally important consideration is if the material contains toxicity (Zoghi *et al.* 2022).

From the concept of construction and material life cycle, each phase has a different degree of impact on deconstruction. Researchers and innovative practitioners are beginning to use design for deconstruction (DfD) and other ways of creating deconstruction cycles based on the life cycle of various building components (Carvalho Machado *et al.* 2018; Kendall 1999). Generally, execution, the requirements and demands, and design of deconstruction are the top three important phases that determine the scale of deconstruction, while disposal to landfill is what deconstruction should avoid, and it has the least impact on deconstruction (Koc & Okudan 2021).

Höglmeier *et al.* (2017) study the material life cycle and focuses on the deconstruction process after the material is reused. He considers the possibility that materials eventually become biochemical products and energy carriers and found that the focus on particle- and fiber-based products can be further optimized.

In addition to materials, the resources that will be consumed during deconstruction, such as landfill areas, groundwater, and oil and gas, can be reduced by 51% if the deconstruction activity is well designed (Ding *et al.* 2016). As discussed above, this study groups different types of renewable and recyclable material from deconstruction together, groups different types of energy related resources such as oil and gas together, and considers landfill and groundwater resources.

2.3 ECONOMY CRITERIA

The relationship between economic development and deconstruction is briefly reviewed. Elefante (2012) looks from an economic point of view, focusing on the secondary space planning and green performance of buildings. Kaza *et al.* (2018) discusses the impact of the economy on material recycling and reuses from a macro-economic perspective. Countries with lower GDP have lower levels of urbanization and lower technological levels, so more building materials are discarded rather than recycled. On the other hand, the transportation cost to owners, contractors, or other stakeholders in the activities of dismantling and disposing of waste, the biosafety disposal of hazardous materials, and the business interests brought about by deconstruction are also important factors that determine the progress of the project (Wang *et al.* 2009). The selection of potential deconstruction projects is similar, and the same factors are also reflected in the process of processing C&D waste (Wu *et al.* 2016).

In general, the previous studies show that one of the purposes of deconstruction is to restore or improve the economic returns to the government and owners, while the above-mentioned literature expounds on the relationship between them from the three aspects of regional economic development, cost, and interest. To summarize, the business interest and regional development are more interesting to government decision-makers, and the biosafety disposal and transportation cost may affect stakeholders' decision on deconstruction.

2.4 BUILDING-TYPE CRITERIA

The literature on the deconstruction possibility of different building types is considered. When considering the recycling of building materials, Ding *et al.* (2016) found that building type will affect the quantity and quality of demolition waste instead of deconstruction. In their quantitative research, Ding *et al.* found diverse waste during demolition for three types of buildings: residential, commercial, and public and industrial buildings, which could be reduced and the materials could be reused by deconstruction. Instead of waste reduction, deconstruction on commercial buildings also helps community leaders improve community revitalization efforts and extend the systemic barriers on deconstruction, such as existing buildings not designed for deconstruction (Bertino *et al.* 2021).

Generally, the above three types of buildings: residential, commercial, and public and industrial buildings are the most likely to be deconstructed. Other types of buildings, such as historical buildings, fall under heritage protection, thus restoration is preferrable to deconstruction (Ding *et al.* 2018). The restoration of these buildings also focuses on the building materials, but maintenance and cultural meaning are deemed to be higher values (Plevoets & Van Cleempoel 2013). When trying to repair historical buildings, other factors such as climate change and historical development must also be considered (Elefante 2007). Hence, buildings deemed to be historic will generally not be considered as potential deconstruction projects. Therefore, this study focused on the above three types of building deconstruction.

Besides the above four categories, social impact and building attributes as noted below are additional important indicators that could contribute to the decision of deconstruction instead of demolition. However, for these factors were not used in the analysis because they did not reflect the values of the experts interviewed.

2.5 SOCIAL IMPACT ON DECONSTRUCTION

Anuranjita *et al.* (2018) concluded that decision-makers prefer deconstruction rather than demolition by two main social impacts: jobsite safety and community involvement, where jobsite safety includes reduced potential injury and hazardous material exposure, while community involvement includes the job creation, training, and community engagement. All these social impacts could contribute to the decision of deconstruction, especially in areas of historic disinvestment. For Pittsburgh, the spatial distribution of abandoned and vacant houses is highly correlated with areas that have suffered from long-term racial discrimination and disinvestment, which has led to significant psychological harm for residents (Teixeira & Zuberi 2016).

However, demolition may also cause neighborhood polarization, and non-consideration of residents' actual needs since most demolition programs are completely market driven (Trop 2017). Trop also concludes that it is still too early to determine general social impact when demolition is in progress. Based on the above complexity, social impact is discussed separately for this experiment. Besides external factors, building attributes themselves also affect the deconstruction decision-making.

2.6 BUILDING ATTRIBUTES' IMPACT ON DECONSTRUCTION

Building attributes can also be important factors when considering deconstruction. Tatiya *et al.* (2018) concluded that building age and building conditions are main contributors to construction project cost. In addition, government policy makers also rely on the building condition to determine building demolition, which provides opportunities for deconstruction. The PLI in Pittsburgh evaluates the structural condition of buildings annually and provides an inspection score of four different levels of structural danger (PLI 2021). Buildings with higher PLI scores are more likely to be demolished due to public safety and liability concerns.

While the existing literature provides a review of the major criteria related to the advantages and limitations of deconstruction broadly, further research on the influencing factors specific to Pittsburgh is needed. The factors used in the AHP analysis in this paper are shown in Table 1, and the building attributes are discussed separately also to control the levels of AHP. These factors are classified into four criteria and are discussed in detail in Section 3.1.

Table 1: Factors influencing deconstruction processes.

Note: AHP = analytic hierarchy process.

AHP HIERARCHY 1	AHP HIERARCHY 2	AHP HIERARCHY 3
Deconstruction process (decision-making)	Environment	Air pollution
		Health impact
		Fuel consumption
	Resource	Renewable material
		Ground water
		Energy resource
		Landfill resource
	Economy	Business interest
		Biosafety disposal
		Transportation cost
		Urban development
	Building type	Residential buildings
		Commercial buildings
		Public and industrial buildings

This paper integrates the above categories from the perspective that all these factors need to be considered simultaneously by decision-makers. This paper also fills the gap that previous research provides cases from different areas of the US and countries such as Germany, Japan, and China, but there is a lack of research on such Rust Belt cities with abandoned properties such as Pittsburgh and the existing condemned buildings with deconstruction value. Ding *et al.*'s study of landfill site selection concludes the importance of influencing factors is used as a reference for site selection (Ding *et al.* 2018). Deconstruction building selection could also benefit from the AHP factors.

3. METHODS

To determine the most important factors influencing the deconstruction pilot in Pittsburgh, experts, stakeholders, and city officials who are involved in policy decisions of deconstruction identified the relative importance of factors through a list compiled from the literature and ranked the factors accordingly using the AHP method. Factors are then converted into spatial layers to identify potential deconstruction areas through weighted overlay in geographic information systems (GIS) where the weights of layers correlate with weights of factors from AHP. This paper uses this initial experiment to demonstrate the advantages of AHP as a decision-making method and further applies the conclusion of AHP through GIS analysis. Figure 2 shows the relationship between the two methods.

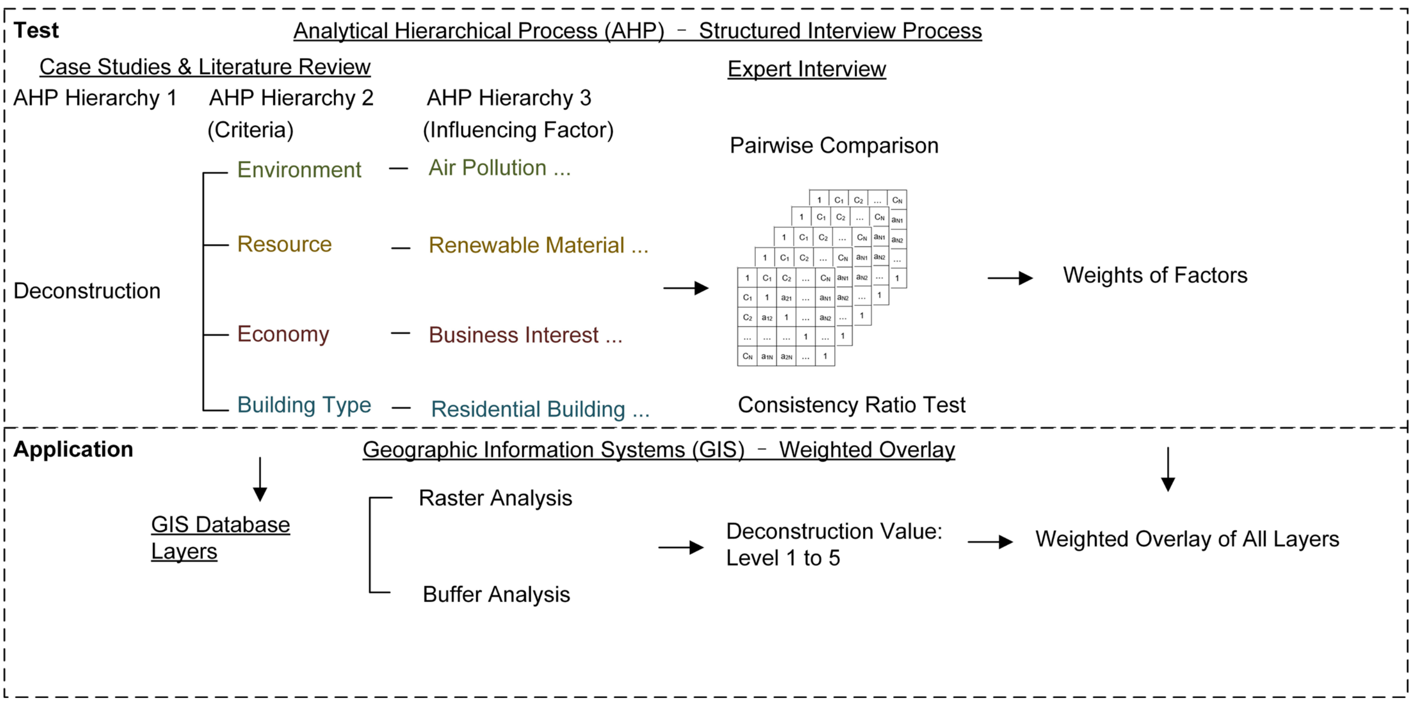

Figure 2: Methodology relationships.

3.1 ANALYTIC HIERARCHY PROCESS (AHP)

The AHP is used to integrate the opinions of experts and distinguish the importance of each factor (Ding *et al.* 2018). AHP is a mathematical method for decision-making that uses effective weighting coefficients and includes an examination of the inconsistency among the experts' opinions (Koc & Okudan 2021). The steps to apply AHP to determine influencing factors are described below.

- *Step 1. Clarify the scope of experts*

  The knowledge of experts is the foundational layer and main determinant of AHP analysis. Experts in the construction industry, academia, and politics who have participated in demolition or deconstruction projects, have research experience, or have management experience are the first choices. The sample size of experts needs to reach a certain level. Generally, the greater the number of experts, the more reliable the ranking of the importance of factors obtained by AHP, and the more reasonable the final decision-making conclusions obtained. However, Tatiya *et al.* (2018) optimized the impact of the number of experts and demonstrated that 11 experts could reach extremely reliable conclusions, and three experts are sufficient to reach preliminary conclusions in the deconstruction industry. Research in the construction industry also develops a robust AHP hierarchy on detecting risks for contractors on highway projects with only four experts' responses, and another research study on landfill selection only contains five experts to develop a site-selection model for landfilling in Shenzhen, China (Ding *et al.* 2018; Zayed *et al.* 2008). While ensuring the diversity of expert backgrounds, this research selected three experts from the PLI and the deconstruction industry in Pittsburgh.

- *Step 2. AHP hierarchy determination*

The AHP model of this study was based on the literature review and considered the four most important categories: environment, resources, economy, and building types. For each category, this study considered the most important three or four influencing factors and constructed an AHP model with two layers.

- *Step 3. Data collection*

The basis of AHP is to obtain the relative weight of factors through pairwise comparison. Therefore, this study collects data by asking experts to compare the factors in the same criterion. The expert's answer will fluctuate between $\frac{1}{5}$ and 5, as detailed in Table 2. The weight relationships represented by different numbers are as follows. The five-point scale is preferred in landfill site selection and policy decision-making with GIS analysis, which is practical for real-world planning and decision-making of the demolition and construction industry (Wang *et al.* 2009).

Table 2: Relative weight explanation.

NUMBER	EXPLANATION
$\frac{1}{5}$	The latter is extremely more unimportant than the former
$\frac{1}{3}$	The latter is slightly more unimportant than the former
1	The latter is equally important as the former
3	The latter is slightly more important than the former
5	The latter is extremely more important than the former

Note: The middle value of the above option numbers means that the relationship between the pair of factors is in the middle of the two dimensions.

- *Step 4. Consistency check*

AHP checks and controls the inconsistency through a consistency index, CI. By comparing the CI with that for a randomly generated index (RI), the relational inconsistency on the consensus ratio (CR) of the expert is eliminated. Saaty (2004) recommends that CR ≤ 0.1. Otherwise, it means that the expert has a contradiction in the pairwise comparison of certain factors. CR is calculated as follows:

$$\mathrm{CI} = \frac{\lambda_{max} - n}{n-1} \tag{1}$$

$$\mathrm{CR} = \frac{CI}{RI} \tag{2}$$

where λ_{max} is the largest or principal eigenvalue of the matrix, n is order of the matrix and CI is the consistency index (Şener *et al.* 2010).

- *Step 5. Determine the weight of each influencing factor*

The weight vector W is then determined from the matrix:

$$W = (\mathrm{d}(A1),\ \mathrm{d}(A2),\ldots,\mathrm{d}(An))^{T} \tag{3}$$

The final weight W_i is the arithmetic mean of the weight from each expert W_{ij}:

$$W_i = \frac{1}{n}\sum W_{ij} \tag{4}$$

Based on the above analysis process, the importance of different influencing factors to Pittsburgh's deconstruction and their weights is obtained.

3.2 WEIGHTED OVERLAY ANALYSIS

To answer which areas or properties are best suited for deconstruction, the areas were ranked based on the above factors and their weights, where the factors were converted to map layers through geographic data, and the weights analyzed by AHP were used as weights of layers for overlay. This map-based ranking method is used for site selection research and feasibility analysis (Natesan & Sarkar 2008; Wang *et al.* 2009). By weighting layers with weights from AHP, the higher ranked area represents areas with the highest deconstruction value considering all factors and weighted overlay layers (Ding *et al.* 2018; Şener *et al.* 2010). The steps for weighted overlay analysis are as follows.

- *Step 1. Data acquisition*

  Public geographic data are used to represent AHP factors. The public website of the City of Pittsburgh (2021a) and the public geographic information website of Pennsylvania and Pittsburgh provides geographic information data aligned with the various factors (WPRDC 2021). Detailed base data are shown in Table 3 and organized by the AHP factors, the base data, and the relationship to the characteristics or distance from the project site. Geographic data above are then analyzed with buffer analysis (step 2a) or raster analysis (Step 2b) based on whether the factor it presents can be expressed by distance. The details are discussed in Section 4.2. More official data could be used for further government decision-making using the same approach in this experiment.

AHP FACTORS	BASE DATA	RELATIONSHIP
Air pollution	Air quality from monitor in Pittsburgh	Raster by characteristics
Health impact	Pollutant and asbestos from demolition and renovation	Raster by characteristics
Fuel consumption	Building carbon footprint	Raster by characteristics
Renewable material	Condemned buildings estimation	Raster by characteristics
Ground water	Ground water supply stations	Buffer by distance
Energy resource	Oil and natural gas energy supply stations	Buffer by distance
Landfill resource	Landfill sites	Buffer by distance
Business interest	Building market value	Raster by characteristics
Biosafety disposal	Asbestos amount	Raster by characteristics
Transportation cost	Main roads	Buffer by distance
Urban development	Building market value	Raster by characteristics
Building types	Condemned buildings estimation	Raster by characteristics

Table 3: Relationship between analytic hierarchy process (AHP) factors and base data.

- *Step 2a. Buffer analysis*

  Buffer analysis is used to analyze factors that are related to distance or can be expressed by distance (Ding *et al.* 2018). Groundwater resource, energy resource, landfill resource, and transportation cost factors used buffer analysis in this paper, represented by the distance between the project site and the resource or nearest road (Ding *et al.* 2018; Natesan & Sarkar 2008).

  Based on the evaluation method of landfill site selection research, five levels are set respectively based on the distance unit of 500 m (1640 ft, about 0.3 miles): 5 points: < 500 m (1640 ft, about 0.3 miles); 4 points: < 1000 m (3280 ft, about 0.6 miles); 3 points: < 1500 m (4921 ft, about 0.9 miles); 2 points: < 2000 m (6561 ft, about 1.2 miles); and 1 point: < 2500 m (8202 ft, about 1.5 miles) (Natesan & Sarkar 2008).

- *Step 2b. Raster analysis*

  Raster analysis is used to analyze factors with regional characteristics (AlZaghrini *et al.* 2019). All other factors are analyzed by raster analysis. According to the raster distribution, five levels are made by equally dividing the raster data. For both buffer and raster analysis, higher levels represent greater deconstruction value.

- *Step 3. Weighted overlay analysis*

  Weighted overlay analysis uses layers created from buffer and raster analysis. The weight of the layers is the same as the relative weight of factors. With the overlay of levels, neighborhoods with the highest level represent the most possible areas for future deconstruction in Pittsburgh.

4. FINDINGS

The following sections provide the detailed findings of influencing factors of Pittsburgh deconstruction with their importance.

4.1 IMPORTANCE OF INFLUENCING CRITERIA WITH AHP ANALYSIS

Table 4 shows the relative average importance and rank of four criteria influencing Pittsburgh deconstruction. For the three experts interviewed, the most important criterion influencing Pittsburgh deconstruction is the environment criterion with an average relative weight of 0.46. The environment criterion is nearly twice the importance of the resource criterion. Building type is the least important criterion on the decision-making of deconstruction in Pittsburgh.

	EXPERT 1	EXPERT 2	EXPERT 3	AVERAGE WEIGHT	RANK
Environment	**0.46**	**0.39**	**0.52**	**0.46**	1
Resource	0.25	0.28	0.26	**0.26**	2
Economy	0.15	0.24	0.10	0.16	3
Building type	0.14	0.09	0.12	0.12	4
CR[a]	0.09	0.06	0.03	–	–

Table 4: Relative importance and rank of criteria.

Note: [a]The consistency rate for all criteria is < 0.1, indicating that the degree of inconsistency is acceptable.

Table 5 provides the relative average importance and rank of three environmental factors. Among all environmental factors, the most significant impact on deconstruction is the health impact, which includes the effects from hazardous materials and components contained in the project on laborers working on the project and surrounding residents. This factor has not been significantly mentioned in previous studies. However, even though health impact is not the most important factor considered by the first expert, this bias is weakened by the average weight of all three experts. The AHP method averages the weights calculated by experts and lack of consensus among decision-makers. The same phenomenon occurs in Tables 6–8. The importance of health impact further demonstrates why the biosafety disposal of hazardous materials is one of the key tasks of deconstruction.

	EXPERT 1	EXPERT 2	EXPERT 3	AVERAGE WEIGHT	RANK
Health impact	0.20	**0.61**	**0.71**	**0.51**	1
Air pollution	**0.70**	0.29	0.14	**0.38**	2
Fossil fuel consumption	0.09	0.08	0.14	0.11	3
CR[a]	0.07	0.07	0.00	–	–

Table 5: Relative Importance and Rank of Environmental Factors.

Note: [a]The consistency rate for all criteria is < 0.1, indicating that the degree of inconsistency is acceptable.

Another important environmental factor is air pollution, which will also influence the decision-making for deconstruction projects. Additionally, the impact of fossil fuel consumption is relatively small and has a slight impact on the decision-making of the deconstruction.

Table 6 provides the relative importance and rank of four resources factors. Landfill resources are not one of the key resources on which deconstruction activities focus as deconstruction reduces the landfill activities compared with demolition (Seldman 2021; Tatiya *et al.* 2018). The principal factors are the potential impact of groundwater resources and the total amount of renewable and recycled materials brought by the project. Experts conclude that deconstruction projects require more professional equipment, making energy resources affect the choice of deconstruction projects compared with demolition. Excessive energy consumed by machinery has a negative impact.

	EXPERT 1	EXPERT 2	EXPERT 3	AVERAGE WEIGHT	RANK
Renewable and recycle materials	**0.57**	**0.48**	0.32	**0.46**	1
Ground water resource	0.18	0.12	**0.37**	**0.23**	2
Energy resource	0.16	0.16	0.21	0.18	3
Landfill resource	0.07	0.22	0.07	0.13	4
CR[a]	0.03	0.04	0.09	–	–

Table 6: Relative importance and rank of resources factors.

Note: [a]The consistency rate for all criteria is < 0.1, indicating that the degree of inconsistency is acceptable.

Table 7 provides the relative importance and rank of four economic factors. Regardless of the perspective of experts, the most important economic factors are business interests and the additional cost of handling toxic and hazardous materials. Although the processing of recyclable materials may go through multiple processes, the cost of transportation is not the most important consideration for deconstruction projects. The choice of deconstructed projects will only be slightly affected by the development of different neighborhoods.

	EXPERT 1	EXPERT 2	EXPERT 3	AVERAGE WEIGHT	RANK
Business interest	**0.60**	**0.48**	0.24	**0.46**	1
Biosafety disposal cost	0.22	0.20	**0.57**	**0.23**	2
Transportation cost	0.10	0.20	0.12	0.14	3
Neighborhood development	0.06	0.09	0.06	0.08	4
CR*	0.08	0.04	0.04	–	–

Table 7: Relative importance and rank of economic factors.

Note: [a]The consistency rate for all criteria is < 0.1, indicating that the degree of inconsistency is acceptable.

Table 8 provides the relative importance and rank of three building type factors. The deconstruction of residential buildings comprises most of the deconstruction of Pittsburgh. Therefore, the deconstruction of these types of buildings is also the focus of all experts. Although commercial buildings have a very high possibility of deconstruction, Pittsburgh has not yet considered deconstructing commercial buildings. Some commercial buildings have very special materials and components, which are often professionally customized. This factor will highly impact the deconstruction project decisions in Pittsburgh.

	EXPERT 1	EXPERT 2	EXPERT 3	AVERAGE WEIGHT	RANK
Residential	0.28	**0.63**	**0.63**	**0.52**	1
Commercial	**0.58**	0.10	0.25	**0.32**	2
Public and industrial	0.13	0.25	0.10	0.16	3
CR[a]	0.07	0.02	0.02	–	–

Table 8: Relative importance and rank of building type factors.

Note: [a]The consistency rate for all criteria is < 0.1, indicating that the degree of inconsistency is acceptable.

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These findings provide the relative importance of different factors in the same criterion. The weights of factors are then used for weighted overlay layers to find the neighborhoods that have a higher deconstruction value considering all factors. The next section shows the detailed findings for the overlay analysis.

4.2 AREAS WITH HIGH DECONSTRUCTION VALUE IN PITTSBURGH

Figure 3 shows the maps of air pollution, health impact, and fuel consumption. Overall air quality, pollutant, and asbestos data of commercial buildings' demolition, and building carbon footprint representing fuel consumption of the Pittsburgh area are averaged by neighborhood, which is consistent with research on the different construction scenarios according to construction frequency (Assefa & Ambler 2017). The level classification adopts the method of raster analysis and a higher deconstruction score represents a higher value which has less air pollution, asbestos pollution, and fuel consumption.

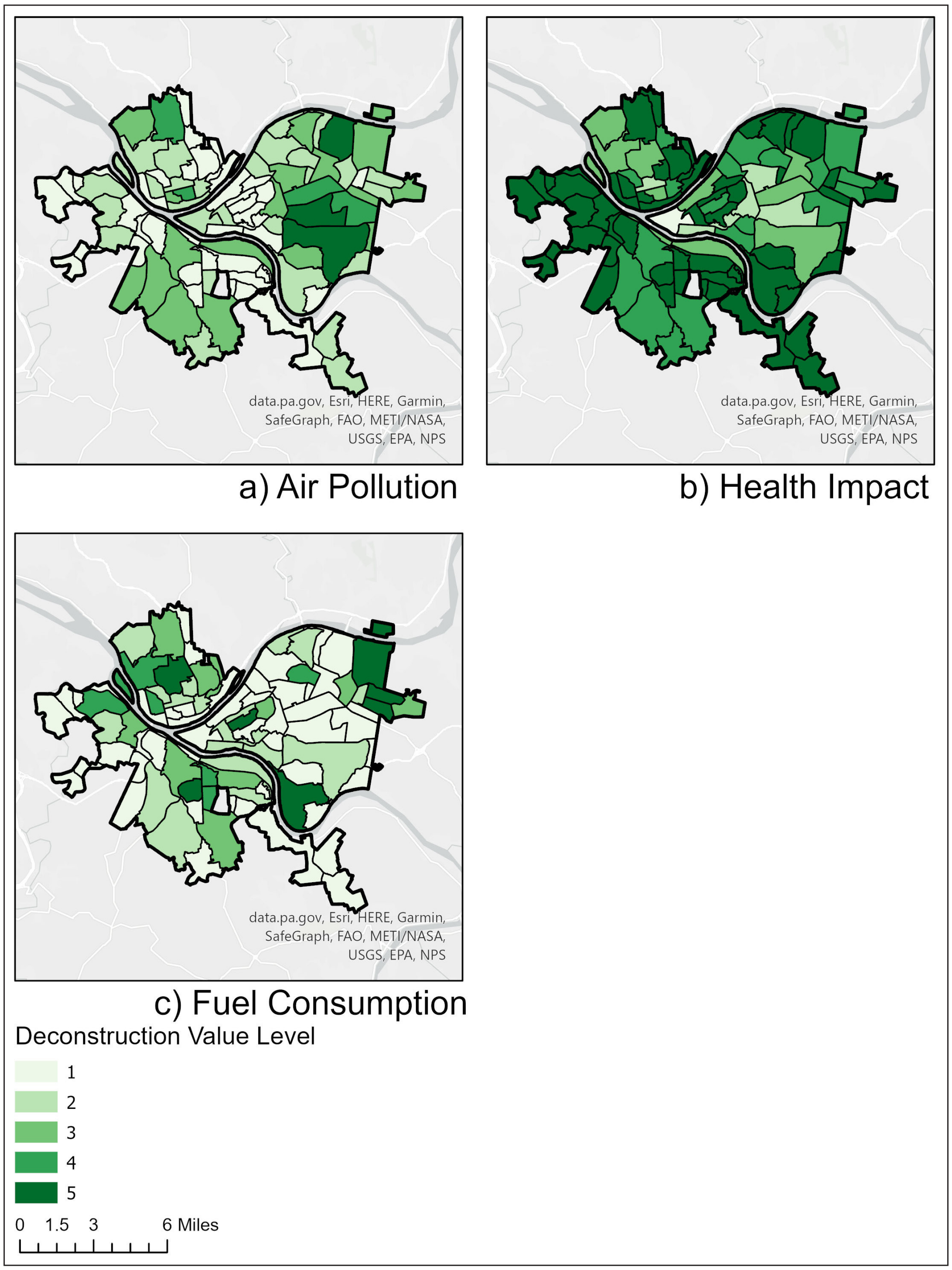

Figure 3: Layer of air quality, health impact and fuel consumption.

Sources: https://data.wprdc.org/dataset/allegheny-county-air-quality (air quality), https://data.wprdc.org/dataset/allegheny-county-asbestos-permit (health criteria), https://data.wprdc.org/dataset/allegheny-county-building-footprint-locations1 (fuel consumption).

Figure 4 shows the result for potential deconstruction areas only considering the environmental factors. When considering these environmental factors, the areas of Pittsburgh far from the city center have a higher potential for deconstruction, and Highland Park has the highest possibility of deconstruction. Areas with a deep color mean that these areas can better meet the requirements of these factors when all three environmental factors are weighted according to the AHP. Here, air pollution and health impact dominate the choice of regions because of the high percentage of weight.

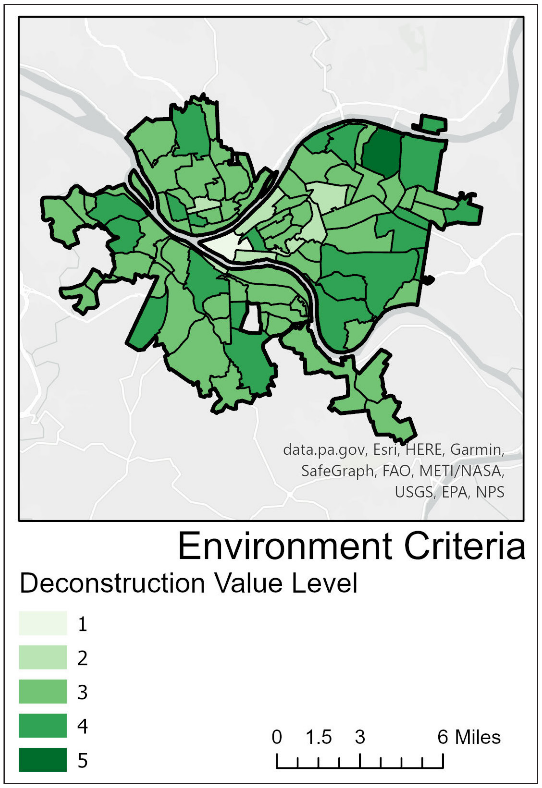

Figure 4: Layer of environment criterion.

Figure 5 shows the maps for landfill, groundwater, energy, and recycling materials. The distance between the potential deconstruction project sites to the landfill area, ground water supply stations, and oil and natural gas energy supply stations in Allegheny County represents the buffer analysis of landfill, groundwater, and energy. The amounts of recycling materials in the map are estimated based on the number of condemned buildings in Pittsburgh neighborhoods due to the lack of specific information on the quantity of building recyclable materials.

Figure 6 shows the process and result for potential deconstruction areas only considering four resources factors. This paper creates buffer zones around different data points according to the buffer distance to build areas that meet the requirements of the factors and divides them into five levels. The area located in the center of the buffer is closer to the location of resource facilities. Areas of Middle Hill best meet the resource requirements. Some areas with resource advantages are located on both sides of the riverbank or distributed in areas where condemned buildings are concentrated.

Figure 7 shows the maps of urban development, transportation cost, biosafety disposal cost, and business interest. The map for urban development and business interest is estimated by the market value of existing buildings in Pittsburgh. The transportation cost map was developed by analyzing the distance from different condemned buildings to the main road. The farther the distance, the higher the transportation cost. The biosafety disposal map focuses on the asbestos information and is calculated by the amount of asbestos.

Figure 8 shows the process and result for potential deconstruction areas only considering four economic factors. The influence of economic factors has led to the spread of potential deconstruction areas. Most blocks are challenging to simultaneously obtain good benefits and spend less.

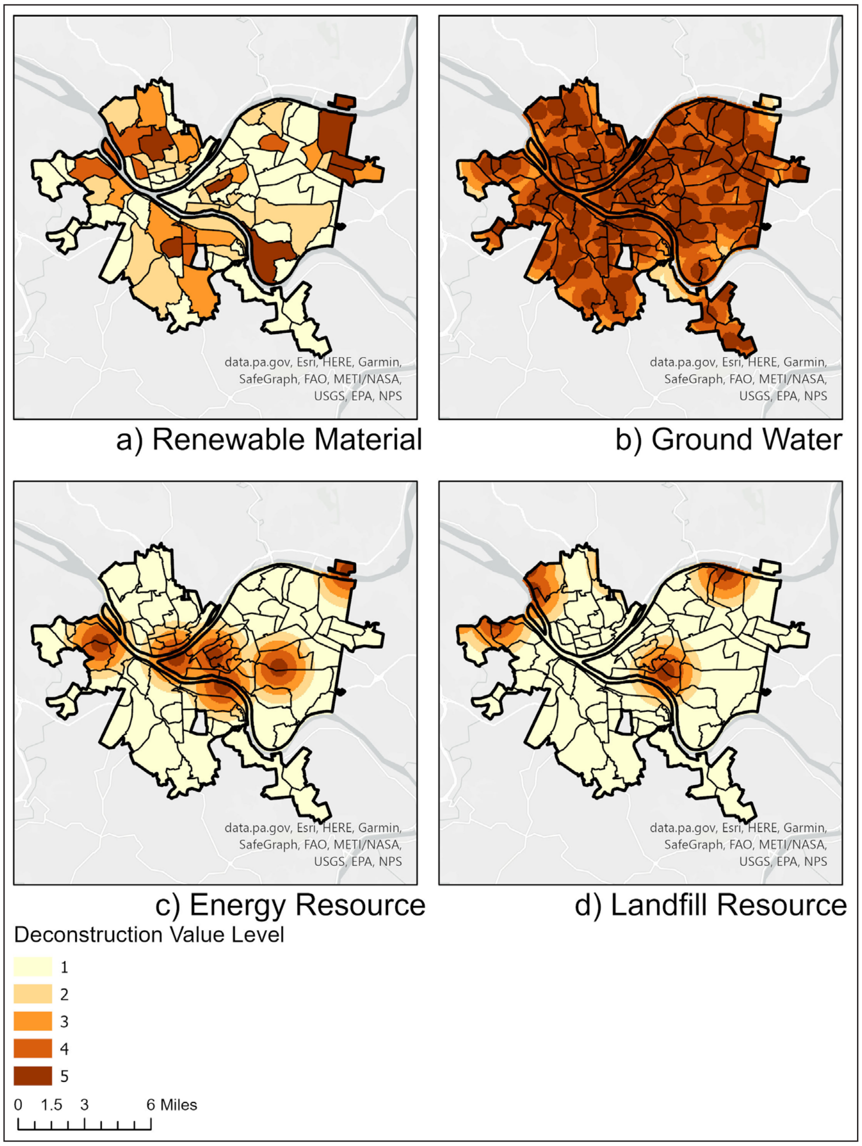

Figure 5: Layer of landfill, ground water, energy and material resources.

Sources: https://www.dep.pa.gov/Business/Land/Waste/SolidWaste/MunicipalWaste/MunicipalWastePermitting/Pages/MW-Landfills-and-Resource-Recovery-Facilities.aspx (landfill), https://data.wprdc.org/dataset/city-water-features (groundwater), https://data.wprdc.org/dataset/allegheny-county-energy-and-water-use (energy), https://pittsburghpa.gov/pli/condemned-under-contract-razed-properties (materials; City of Pittsburgh, 2021a).

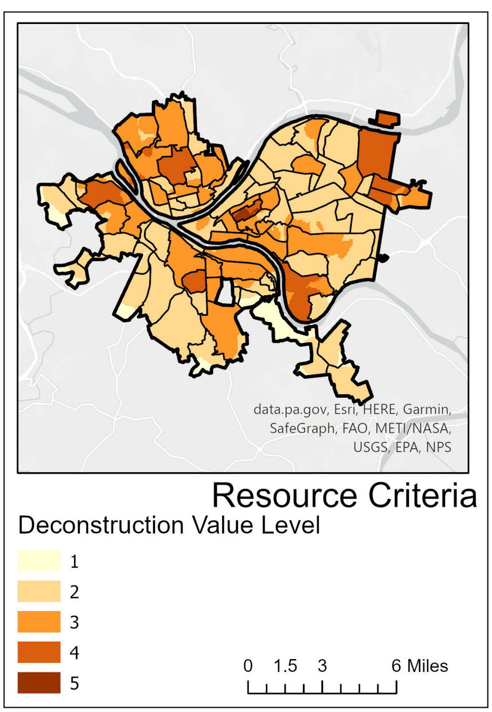

Figure 6: Layer of resource criterion.

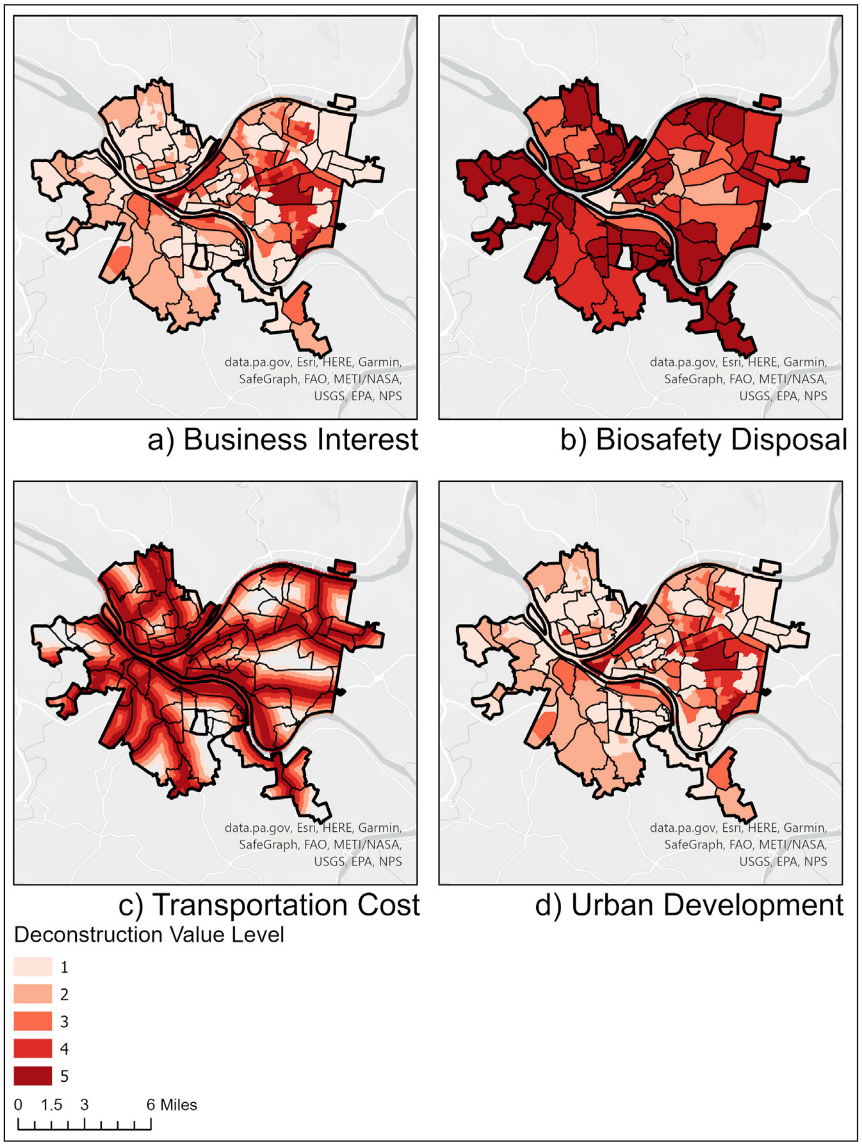

Figure 7: Layer of business interest, transportation cost, biosafety disposal and urban development.

Sources: https://data.wprdc.org/dataset/market-value-analysis-allegheny-county-economic-development (urban development and business interest), https://www.census.gov/cgi-bin/geo/shapefiles/index.php?year=2021&layergroup=Roads (transportation cost), https://data.wprdc.org/dataset/allegheny-county-asbestos-permit (biosafety disposal cost).

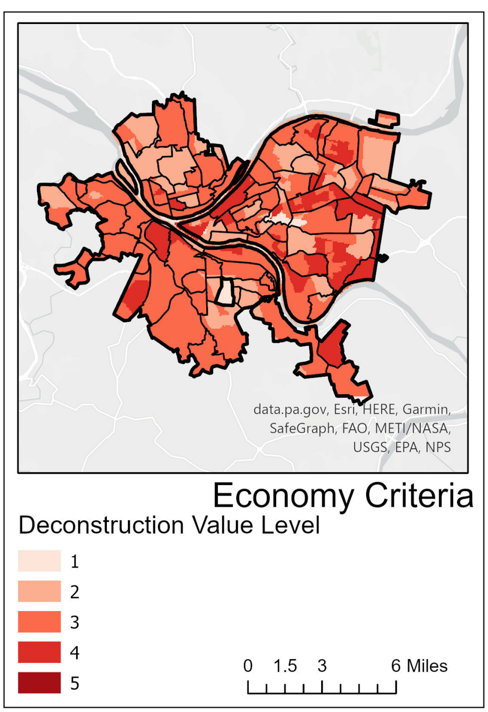

Figure 8: Layer of economy criterion.

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Figure 9 shows the basic maps for the condemned residential building, condemned commercial buildings, and condemned public and industrial buildings. These maps are developed based on the distribution of condemned buildings in the Pittsburgh area. The data of condemned buildings are averaged by neighborhoods.

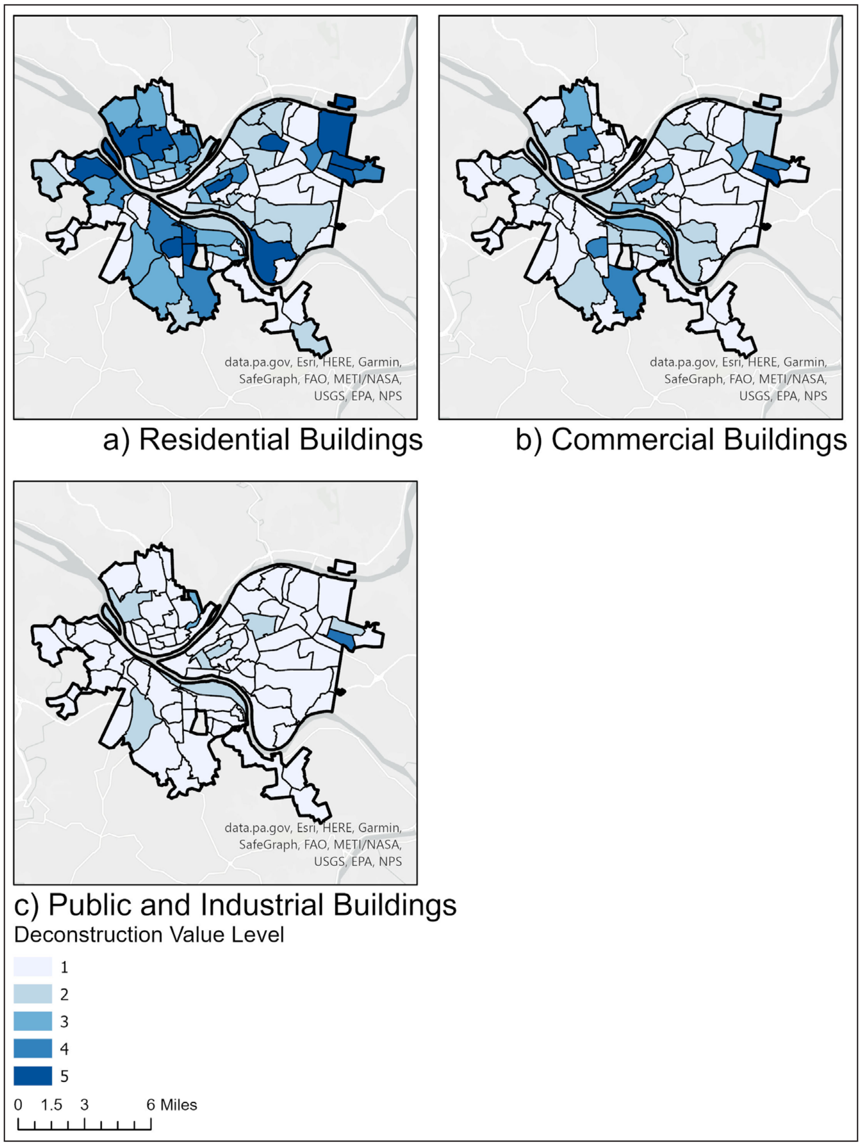

Figure 9: Layer of residential, commercial, and public and industrial buildings.

Source: https://pittsburghpa.gov/pli/condemned-under-contract-razed-properties (City of Pittsburgh, 2021a).

Figure 10 shows the process and result for potential deconstruction areas only considering building type factors. When only building types are considered, areas with more condemned residential buildings have a higher probability of deconstruction.

Figure 11 shows the potential deconstruction areas in Pittsburgh considering all factors from the four criteria. Condemned buildings in most areas have a higher level of deconstruction value. In terms of spatial distribution, these areas are far from the city center. Those areas could potentially be the focus of the Pittsburgh deconstruction pilot and contain more condemned properties not only owned by the city than others.

Figure 12 shows the distribution of all condemned buildings with their deconstruction value calculated by all layers above. Buildings with a dark color are the recommendations from this paper estimated by the experts' opinions and GIS data. However, there are also some inconsistent areas such as Homewood South, East Hills, Upper Hill, Beltzhoover, and Perry South, which could contain more condemned buildings that could be deconstructed.

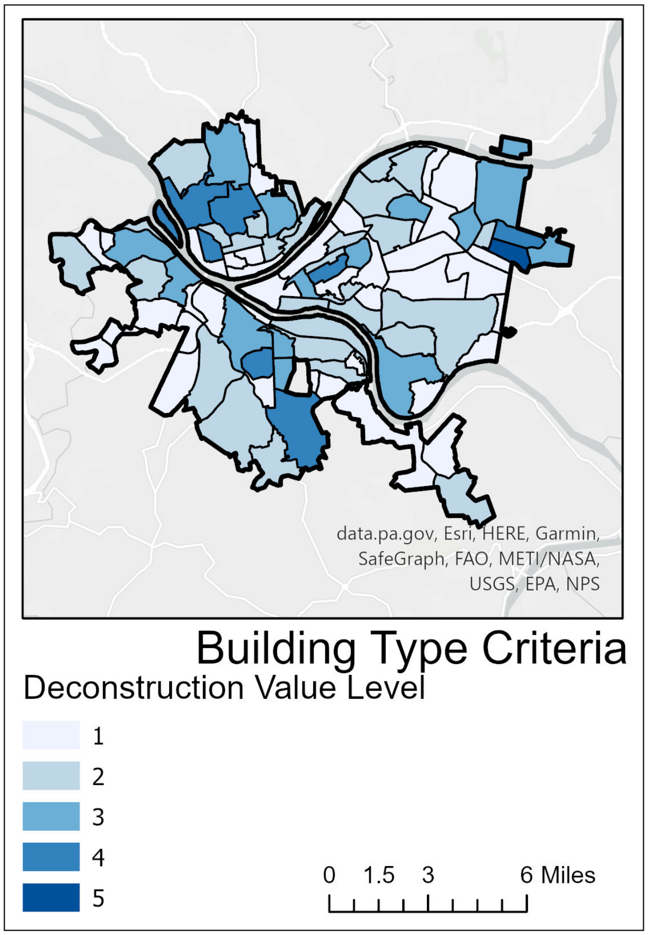

Figure 10: Layer of building type criterion.

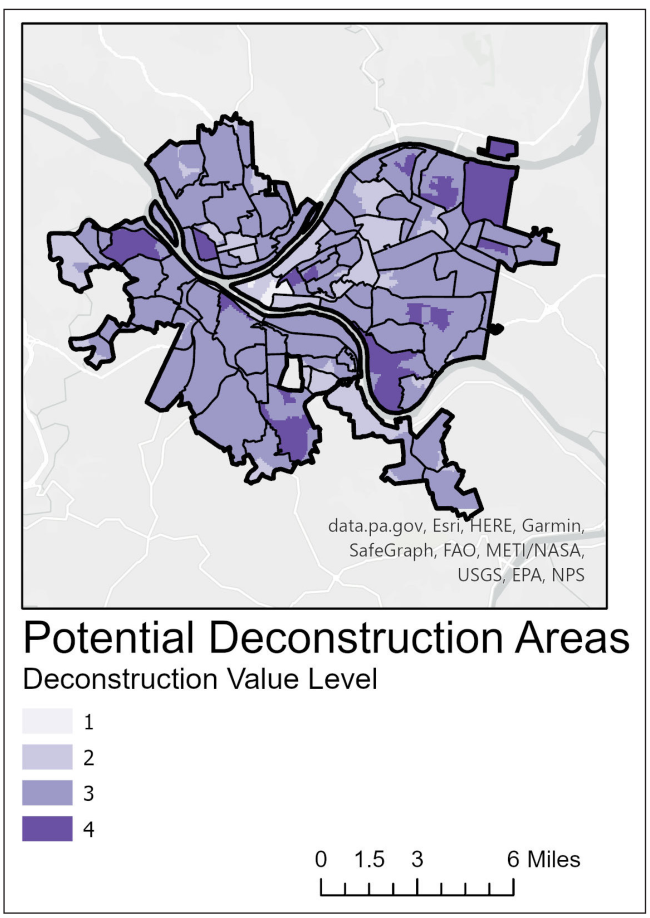

Figure 11: Potential deconstruction areas in Pittsburgh.

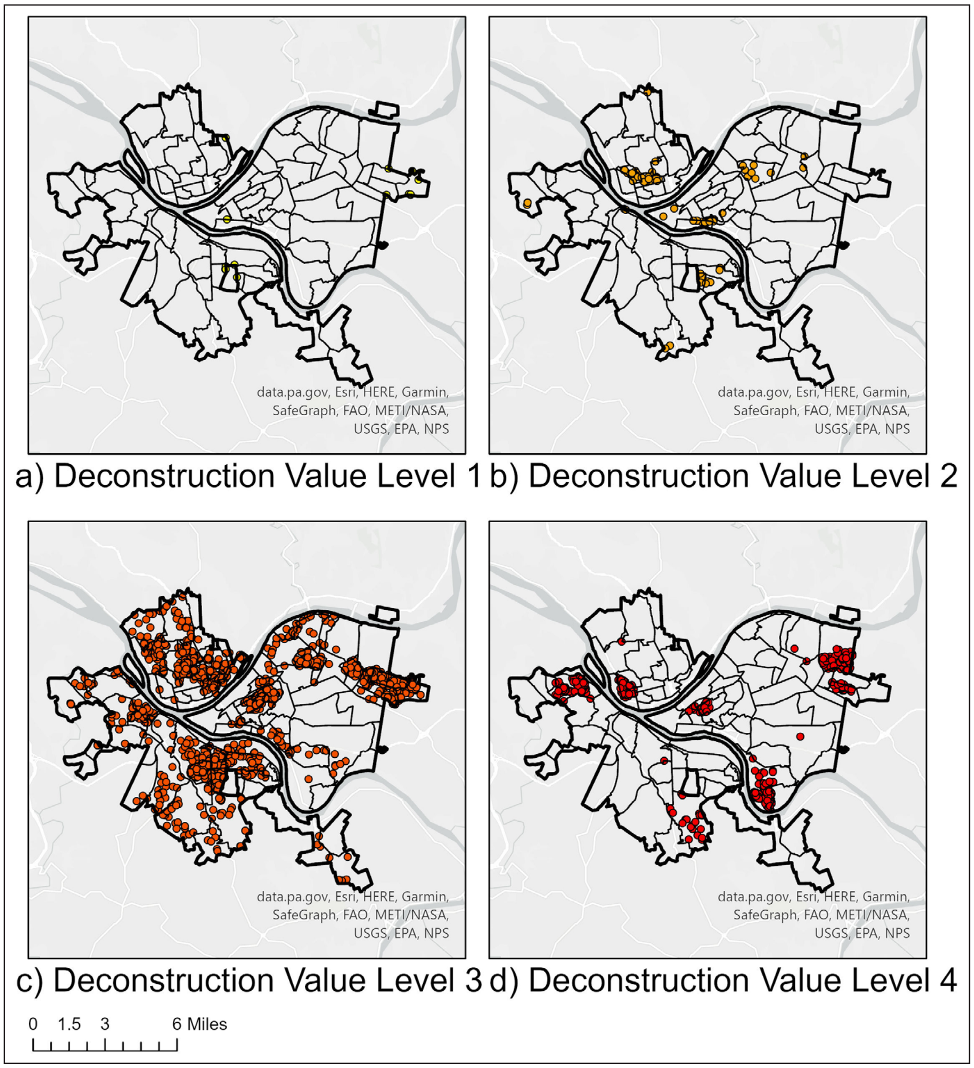

Figure 12: Deconstruction value of all city-owned condemned buildings in Pittsburgh.

5. CONCLUSIONS

This analysis illustrates the potential benefits of combining analytic hierarchy process (AHP) and geographic information systems (GIS) analysis to make decisions about targeted deconstruction in the City of Pittsburgh. However, the method could be expanded and adapted by others to provide a meaningful analysis of the values of many diverse stakeholders in other places.

Figure 13 shows the relative average weights integrated with the AHP model based on the values of the experts interviewed for this study. The environment criteria receive an overall weight of 0.46, with the resource criteria weighted at 0.26, economy at 0.16, and building type at 0.12. This indicates that environmental protection is the most important consideration in Pittsburgh, followed by resource effectiveness. Economy and building type are comparatively minor considerations. However, even those influencing factors with the least weight, such as the urban development factor in the economic criterion which has a weight of 0.08, are still important to the decision-making of deconstruction in Pittsburgh according to the experts.

Figure 14 shows the relationship between the distribution of condemned buildings and the deconstruction value by areas. Figure 14c,d considers the greatest deconstruction value, containing 73.3% and 21.2% of condemned buildings in Pittsburgh, which interprets the reliability of the test results in this paper.

Considering the other major attributes related to deconstruction: the DCP score from the Department of City Planning representing the structural value of the building and the built year representing the building age, Figure 15 shows the relationship between areas with greatest deconstruction value and those building attributes.

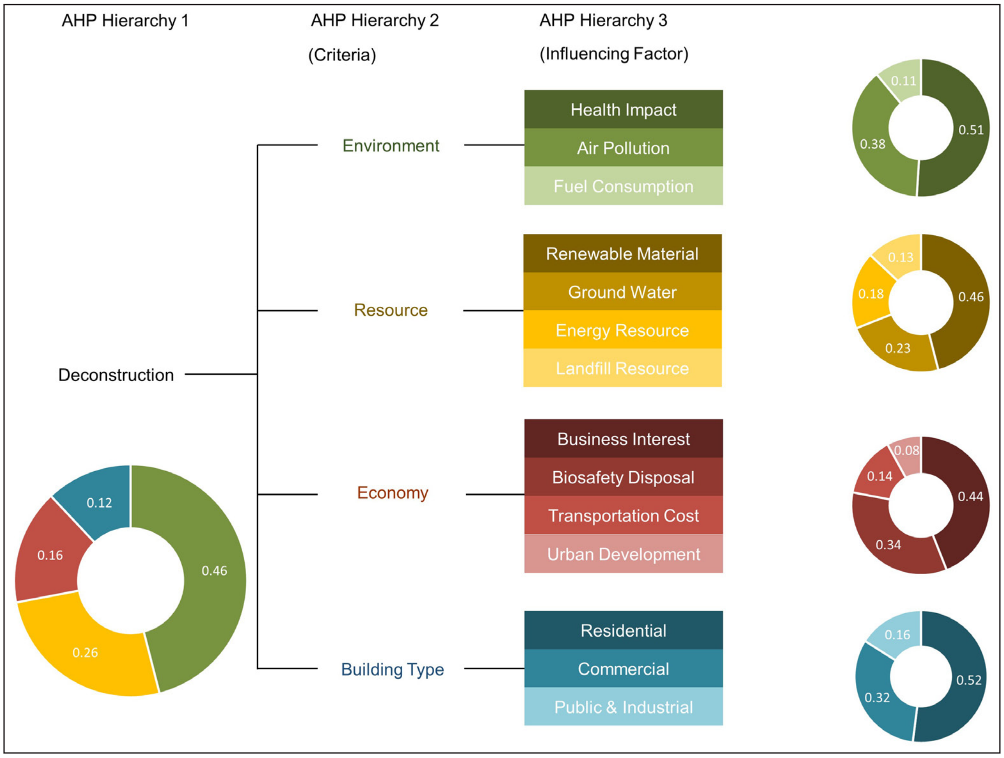

Figure 13: Relative weights with the analytic hierarchy process (AHP) model.

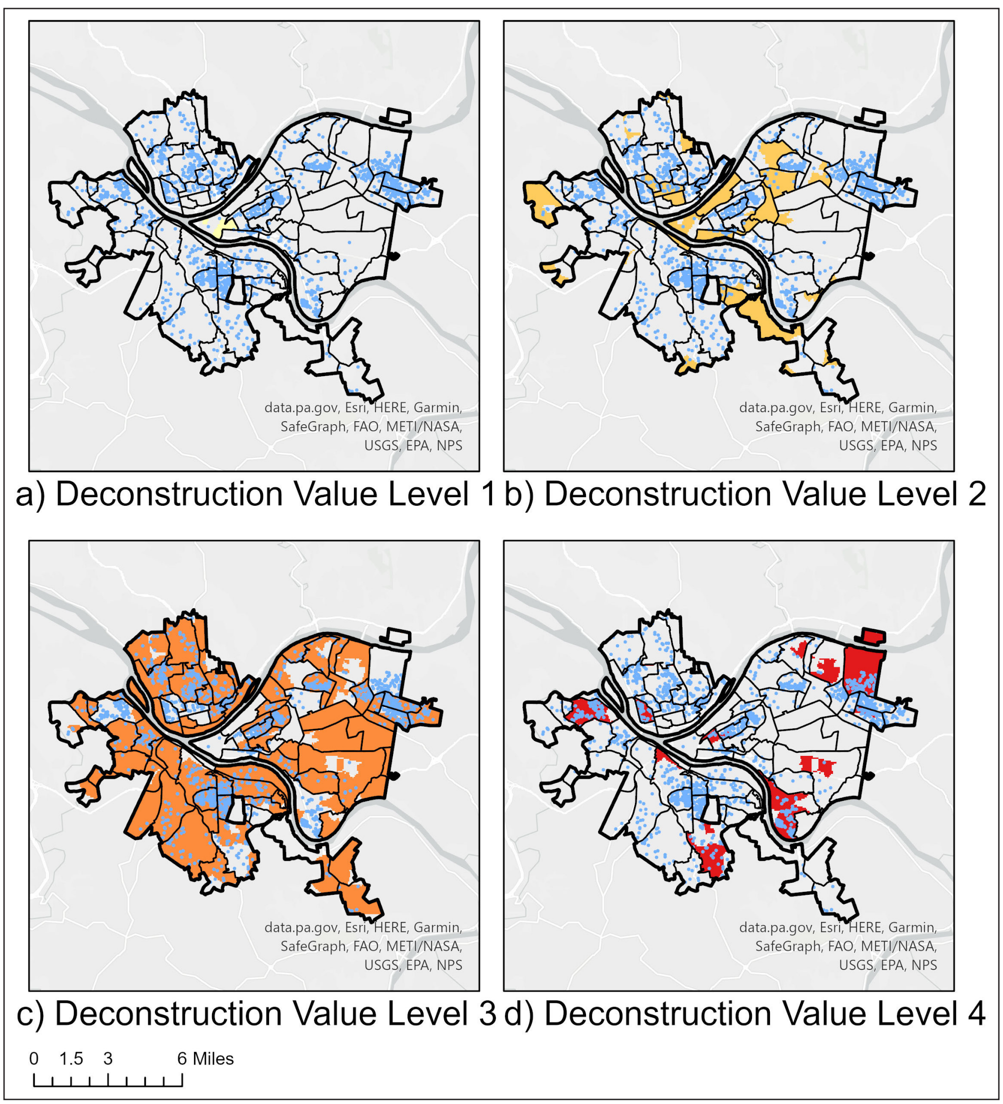

Figure 14: Relationship between the distribution of condemned buildings and the potential areas in each level.

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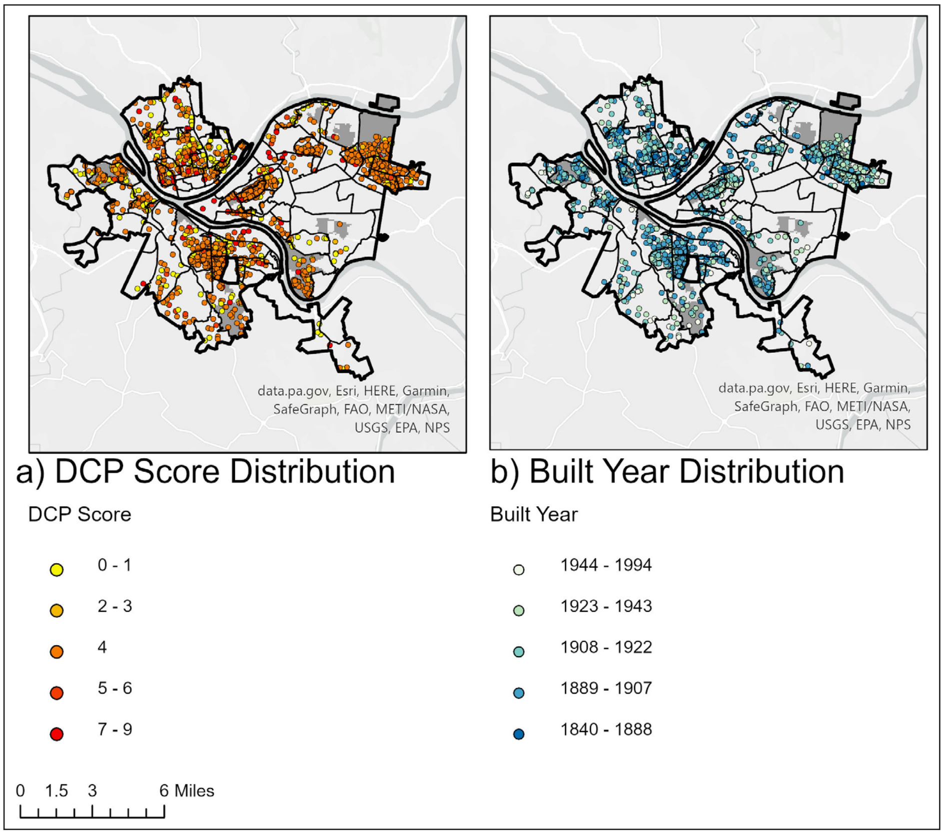

Figure 15: Distribution of condemned buildings by attributes and the potential areas in deconstruction level 4.

5.1 RECOMMENDATIONS FOR PITTSBURGH

For Pittsburgh's pilot, it is recommended that condemned buildings within areas far from the center of the city (Figure 14c,d) be targeted considering all factors and their relative importance according to the experts. To enhance the decision-making process, it is recommended that the city first includes more experts to have more stakeholders' voices. For further discussion, the authors encouraged the inclusion of local residents as candidates on AHP with adjusting factors to include both short- and long-term social impacts to invest in the community and avoid negative impacts on both social and economic sides (Trop 2017). A long-term social impact can be analyzed considering processes of design for deconstruction, onsite work, and community reconstruction by continuing applying this process.

Based on the five-level classification maps, the final map only shows four levels of deconstruction value. The lack of the fifth level is that none of the census tracts or neighborhoods in Pittsburgh meets the best level of all factors in the AHP model. It also interprets why some areas do not match the distribution of condemned buildings. More specific definitions of AHP factors and the relevant geographic data would enhance the analysis.

Factors such as the real land and architecture value, the associated community reinvestment, and detailed building attributes should be considered to integrate more concerns since it is a city-level policy decision. Besides the deconstruction project selection, materials' cascading utilization and life-cycle reuse could also be considered for material tracking and other purposes.

The collection and utilization of datasets are the key factors affecting GIS decision-making. Areas with the highest deconstruction value in Figure 11 may contain more potential properties that are not inspected by the City of Pittsburgh's Department of Permits, Licenses, and Inspections (PLI). More structural inspection in those areas and a more comprehensive properties' dataset are needed to fill the gap.

As a preliminary experiment, the authors encouraged the decision-makers to focus on this proof of concept of the group decision-making process and use more official and detailed datasets for their own purposes.

5.2 RECOMMENDATIONS FOR FUTURE RESEARCH

When multiple projects are reclassified, the deconstruction policy of the Pittsburgh area will be able to set different strategic goals and promote the implementation of the deconstruction policy. Before applying this decision-making process to broader use cases, some recommendations and challenges should be considered. Continuously optimizing the AHP model by adjusting factors and increasing the number of experts to more than 11 through preliminary conclusions can make the AHP model more robust (Tatiya *et al.* 2018). The AHP would also benefit from experts with real decision-making power or deconstruction experience. Insights on real deconstruction policies, projects, and decision-makings help experts avoid the inconsistency between decision-makers and professionals. The diverse backgrounds of stakeholders of deconstruction should be included such as the municipal government, owners, contractors, designers, and residents. Therefore, diverse feedback will help obtain rankings of different factors and serve different teams, which leads to the complete decision-making process of the life cycle of deconstruction.

Although AHP analysis separates the comprehensive question into small pieces, experts are making decisions based on their own interests. Aggregating individual judgments through a weighted geometric mean instead of averaging by empowering decision-making weights to experts could reach acceptably cardinal consensus and reduce the inconsistency of the group (Dong *et al.* 2010; Escobar *et al.* 2004). When analyzing the AHP results through more participants, the above methods could be used to increase the accuracy of group decision-making. In addition, the multi-hierarchy models in AHP also allow the relative importance of factors to be identified intuitively, even avoiding asking experts to compare the importance of two unrelated factors. Evans *et al.* (2021) compared 28 factors simultaneously and lost insights on relatively low weighted factors since their weights were similar. Therefore, controlling the number of factors at each layer allows all the factors to be analyzed more intuitively in the actual decision-making process.

When reclassifying properties through the process, commercial condemned buildings should be considered more carefully. Based on the discussion in Section 4.1, special materials and components in commercial buildings have great value in reuse and recycling. Other buildings in general may also have unique value for building materials and components. Wood is an example that can be preserved and reused, which extends its life before finally becoming an energy carrier (Höglmeier *et al.* 2017). Different decisions need different levels of details on the factor and data selection. However, with this experiment, stakeholders could demonstrate the initial conclusion and integrate with other methods for deeper proofs.

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AUTHOR CONTRIBUTIONS

ZZ: Conceptualization, methodology, software, formal analysis, writing (original draft); JDL: Conceptualization, writing (review and editing).

COMPETING INTERESTS

The authors have no competing interests to declare.

DATA AVAILABILITY

The interactive GIS analysis maps can also be accessed through the public Esri Dashboard.

REFERENCES

Anuranjita, A., Berghorn, G. H., Bates, D., & **Syal, M. G. M.** (2018). Life cycle assessment framework for demolition and deconstruction of buildings. In C. Wang, C. Harper, Y. Lee, R. Harris & C. Berryman (Eds.), *Construction Research Congress 2018: Sustainable design and construction and education* (pp. 339–349). DOI: https://doi.org/10.1061/9780784481301.034

AlZaghrini, N., Srour, F. J., & **Srour, I.** (2019). Using GIS and optimization to manage construction and demolition waste: The case of abandoned quarries in Lebanon. *Waste Management*, 95, 139–149. DOI: https://doi.org/10.1016/j.wasman.2019.06.011

Assefa, G., & **Ambler, C.** (2017). To demolish or not to demolish: Life cycle consideration of repurposing buildings. *Sustainable Cities and Society*, 28, 146–153. DOI: https://doi.org/10.1016/j.scs.2016.09.011

Bertino, G., Kisser, J., Zeilinger, J., Langergraber, G., Fischer, T., & **Österreicher, D.** (2021). Fundamentals of building deconstruction as a circular economy strategy for the reuse of construction materials. *Applied Sciences*, 11(3), 939. DOI: https://doi.org/10.3390/app11030939

Carvalho Machado, R., Artur de Souza, H., & **de Souza Veríssimo, G.** (2018). Analysis of guidelines and identification of characteristics influencing the deconstruction potential of buildings. *Sustainability*, 10(8), 2604. DOI: https://doi.org/10.3390/su10082604

Cheshire, D. (2019). *Building revolutions: Applying the circular economy to the built environment*. Routledge & RIBA Publ. DOI: https://doi.org/10.4324/9780429346712

City of Pittsburgh. (2021a). *Condemned, under contract and razed properties*. https://pittsburghpa.gov/pli/condemned-under-contract-razed-properties

City of Pittsburgh. (2021b). *Deconstruction in Pittsburgh*. pittsburghpa.gov/mayor/deconstruction

City of San Antonio. (2017). *Deconstruction and salvage initiative*. https://www.sanantonio.gov/historic/CurrentProjects/Deconstruction#257841108-documents--resources

City of Seattle. (2021). *Construction and demolition waste management*. www.seattle.gov/utilities/construction-resources/collection-and-disposal/construction-and-demolition

Ding, Z., Wang, Y., & **Zou, P. X.** (2016). An agent based environmental impact assessment of building demolition waste management: Conventional versus green management. *Journal of Cleaner Production*, 133, 1136–1153. DOI: https://doi.org/10.1016/j.jclepro.2016.06.054

Ding, Z., Zhu, M., Wu, Z., Fu, Y., & **Liu, X.** (2018). Combining AHP-entropy approach with GIS for construction waste landfill selection—A case study of Shenzhen. *International Journal of Environmental Research and Public Health*, 15(10), 2254. DOI: https://doi.org/10.3390/ijerph15102254

Dong, Y., Zhang, G., Hong, W. C., & **Xu, Y.** (2010). Consensus models for AHP group decision making under row geometric mean prioritization method. *Decision Support Systems*, 49(3), 281–289. DOI: https://doi.org/10.1016/j.dss.2010.03.003

Elefante, C. (2012). The greenest building is … one that is already built. *Forum Journal*, 27(1), 62–72. https://www.muse.jhu.edu/article/494514

Escobar, M. T., Aguarón, J., & **Moreno-Jiménez, J. M.** (2004). A note on AHP group consistency for the row geometric mean priorization procedure. *European Journal of Operational Research*, 153(2), 318–322. DOI: https://doi.org/10.1016/S0377-2217(03)00154-1

Evans, M., Farrell, P., Elbeltagi, E., & **Dion, H.** (2021). Barriers to integrating lean construction and integrated project delivery (IPD) on construction megaprojects towards the global integrated delivery (GID) in multinational organisations: Lean IPD&GID transformative initiatives. *Journal of Engineering, Design and Technology*. DOI: https://doi.org/10.1108/JEDT-02-2021-0070

Ghosh, S., Byahut, S., & **Masilela, C.** (2019). Metropolitan regional scale smart city approaches in a Shrinking City in the American Rust Belt—Case of Pittsburgh, Pennsylvania. *Smart Metropolitan Regional Development: Economic and Spatial Design Strategies*, 979–1021. DOI: https://doi.org/10.1007/978-981-10-8588-8_17

Hines, S. (2021). *Reclaiming wood, lives, and communities: How do we turn a waste stream into an asset that revitalizes cities?* www.learngala.com/cases/urbanwood/

Höglmeier, K., Weber-Blaschke, G., & **Richter, K.** (2017). Potentials for cascading of recovered wood from building deconstruction—A case study for south-east Germany. *Resources, Conservation and Recycling*, 117, 304–314. DOI: https://doi.org/10.1016/j.resconrec.2015.10.030

Kaza, S., Yao, L. C., Bhada-Tata, P., & **Van Woerden, F.** (2018). *What a waste 2.0: A global snapshot of solid waste management to 2050*. World Bank. DOI: https://doi.org/10.1596/978-1-4648-1329-0

Kendall, S. (1999). Open building: An approach to sustainable architecture. *Journal of Urban Technology*, 6(3), 1–16. DOI: https://doi.org/10.1080/10630739983551

Koc, K., & **Okudan, O.** (2021). Assessment of life cycle risks of deconstruction in urban regeneration projects. *Journal of Construction Engineering and Management*, 147(10), 04021137. DOI: https://doi.org/10.1061/(asce)co.1943-7862.0002161

McDonough, W., & **Braungart, M.** (2002). *Cradle to cradle: Remaking the way we make things*. North Point.

Natesan, U., & **Sarkar, C.** (2008). GIS-based approach for optimized siting of municipal solid waste landfill. *Waste Management*, 28(11). DOI: https://doi.org/10.1016/j.wasman.2007.09.032

Plevoets, B., & **Van Cleempoel, K.** (2013). Adaptive reuse as an emerging discipline: An historic survey. In G. Cairns (Ed.), *Reinventing architecture and interiors: A socio-political view on building adaptation*. Libri.

PLI. (2021). *Condemned property demolition engagement*. Engage Pittsburgh, Department of Permits, Licenses, and Inspections (PLI). https://engage.pittsburghpa.gov/pli-demolition-engagement

Saaty, T. L. (2004). Decision making—The analytic hierarchy and network processes (AHP/ANP). *Journal of Systems Science and Systems Engineering*, 13, 1–35. DOI: https://doi.org/10.1007/s11518-006-0151-5

Schultmann, F., & **Sunke, N.** (2007). Energy-oriented deconstruction and recovery planning. *Building Research & Information*, 35(6), 602–615. DOI: https://doi.org/10.1080/09613210701431210

Seldman, N. (2021). *Update on building deconstruction initiatives in several U.S. cities*. Institute for Local Self-Reliance. ilsr.org/update-on-building-deconstruction-initiatives-in-several-u-s-cities/

Şener, Ş., Şener, E., Nas, B., & **Karagüzel, R.** (2010). Combining AHP with GIS for landfill site selection: A case study in the Lake Beyşehir catchment area (Konya, Turkey). *Waste Management*, 30(11), 2037–2046. DOI: https://doi.org/10.1016/j.wasman.2010.05.024

Tatiya, A., Zhao, D., Syal, M., Berghorn, G. H., & **LaMore, R.** (2018). Cost prediction model for building deconstruction in urban areas. *Journal of Cleaner Production*, 195, 1572–1580. DOI: https://doi.org/10.1016/j.jclepro.2017.08.084

Teixeira, S., & **Zuberi, A.** (2016). Mapping the racial inequality in place: Using youth perceptions to identify unequal exposure to neighborhood environmental hazards. *International Journal of Environmental Research and Public Health*, 13(9), 844. DOI: https://doi.org/10.3390/ijerph13090844

Trop, T. (2017). Social impact assessment of rebuilding an urban neighborhood: A case study of a demolition and reconstruction project in Petah Tikva, Israel. *Sustainability*, 9(6), 1076. DOI: https://doi.org/10.3390/su9061076

US EPA. (2018). *Construction and demolition debris generation in the United States*. US Environmental Protection Agency (EPA) Office of Resource Conservation and Recovery (pp. 16–26). https://emea.mitsubishielectric.com/ar/products-solutions/factory-automation/index.html

Wang, G., Qin, L., Li, G., & **Chen, L.** (2009). Landfill site selection using spatial information technologies and AHP: A case study in Beijing, China. *Journal of Environmental Management*, 90(8), 2414–2421. DOI: https://doi.org/10.1016/j.jenvman.2008.12.008

WPRDC. (2021). *Datasets*. Western Pennsylvania Regional Data Center (WPRDC). https://data.wprdc.org/dataset

Wu, H., Wang, J., Duan, H., Ouyang, L., Huang, W., & **Zuo, J.** (2016). An innovative approach to managing demolition waste via GIS (geographic information system): A case study in Shenzhen city, China. *Journal of Cleaner Production*, 112, 494–503. DOI: https://doi.org/10.1016/j.jclepro.2015.08.096

Zayed, T., Amer, M., & **Pan, J.** (2008). Assessing risk and uncertainty inherent in Chinese highway projects using AHP. *International Journal of Project Management*, 26(4), 408–419. DOI: https://doi.org/10.1016/j.ijproman.2007.05.012

Zoghi, M., Rostami, G., Khoshand, A., & **Motalleb, F.** (2022). Material selection in design for deconstruction using Kano model, fuzzy-AHP and TOPSIS methodology. *Waste Management & Research*, 40(4), 410–419. DOI: https://doi.org/10.1177/0734242X211013904

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