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Pre/Re/De-construction: Investigating the Eco-socio-technical Impacts of Construction Waste in Pittsburgh

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EXECUTIVE SUMMARY

This report is the culmination of a 14-week coordinated research project conducted by six Master of Science in Architecture-Engineering-Construction Management (MS AECM) students at Carnegie Mellon University. Each fall semester, all graduating MS AECM students enroll in the *AECM Synthesis Project* course under the direction of Assistant Professor Joshua D. Lee. The course is designed to apply the diverse knowledge and skills that AECM students have acquired during their 16-month program to a critical public interest issue related to the built environment and the topics vary from year to year. In 2019 we focused on analyzing the environmental inequities in Pittsburgh schools. In the fall of 2020, we investigated the impact of COVID-19 on vulnerable communities.

This year we considered the eco-socio-technical impacts of construction and demolition debris. During the first few weeks of the semester the students learned about the global, regional, and local impacts of construction-related debris as well as a wide array of existing mitigation efforts through readings and discussions with experts near and far. We found it quite shocking that building construction and demolition accounts for approximately 169,000,000 tons of debris each year (U.S. Environmental Protection Agency 2018). The aging building stock in the US is a major factor. Locally there are currently 1,700 condemned buildings across the City of Pittsburgh that are slated for removal. To help address this issue the City of Pittsburgh announced in May 2021 they will be initiating a Deconstruction Pilot Program under an executive order by the former Mayor, Bill Peduto. Deconstruction is a systematic process of disassembling whole or parts of a structure to recover maximum economic and public good through reuse and recycling. Armed with this knowledge, students formulated an exciting array of individual research projects and made many helpful observations for those interested in exploring the challenges and potential benefits of pursuing a circular construction economy in Western Pennsylvania.

In “Chapter 1- Barriers to Deconstruction: Visualizing Building Removal in Pittsburgh, Pennsylvania,” Grant Johnson asked a fundamental question, “why isn’t deconstruction standard practice.” Although he found various answers to this question from elsewhere in the literature, Grant wished to dig into the specific reasons related to Pittsburgh, so he used Geographic Information Systems (GIS) maps to visually document the locations of recently demolished buildings in the city, re-photography to illustrate the impact of removing buildings, and expert interviews with local deconstruction experts. Ultimately Grant found that the costs and expediency afforded by standard demolition make it extremely difficult to choose deconstruction, a socially and environmentally preferable practice, because many of the costs are externalized to others. This finding was expanded in the next chapter.

Alyssa Mayorga’s “Chapter 2 - *Just* Deconstruction: Investigating the Social Impacts of Pittsburgh’s Deconstruction Pilot Program,” specifically explores the policy implementations and neighborhood politics related to the former mayor’s executive order. Alyssa’s study uses expert interviews, GIS analysis, and rephotography to answer the following questions, “what are the current plans for the Pittsburgh Deconstruction Pilot Program?” and “what are the potential impacts of concentrating deconstruction within Pittsburgh’s Avenues of Hope.” According to Alyssa’s findings, building deconstruction should not be considered on economic and environmental grounds alone. Mass loss of property, especially in historically disinvested and majority-

minority neighborhoods can have significant impacts on the wellbeing of communities and businesses. Therefore, Alyssa recommends that the properties chosen should be very carefully selected to ensure social justice concerns are considered. The City of Pittsburgh needs to meaningfully engage the Avenues of Hope leadership as soon as possible to create a dedicated plan that creates a community benefit for each vacant lot following deconstruction. The next chapter outlines a way to operationalize a portion of this suggested plan.

In Chapter 3, Rutuja Dhuru offers a “Deconstruction Assessment Feasibility and Toolkit.” Through literature review, case studies, and expert interviews, Rutuja created a multi-step process for identifying which of the 340 city-owned condemned properties should be prioritized for the Deconstruction Pilot Program. The first level of the process documents the property’s length of vacancy, estimated maintenance costs, age and exterior finish. The second level is a visual inspection of the property, and the third level includes a detailed materials assessment. These three steps will help determine the feasibility of the properties for deconstruction and whether it should be a salvage, partial, or full deconstruction. However, it might also help to include a system of prioritization based on local knowledge and preference as outlined in Chapter 4 and Chapter 5.

“Chapter 4 - Analysis of the Major Influencing Factors on Deconstruction in Pittsburgh through Analytical Hierarchical Process (AHP) and Geographic Information Systems (GIS)” by Zehan Zhang provides a rich literature review that highlights a variety of criteria influencing the decision to stabilize, demolish, or deconstruct condemned properties. However, Zehan also found that construction materials and decision-making processes are locally and regionally specific, so it is unclear which factors may be most impactful in Pittsburgh. This chapter uses expert interviews to establish the relative importance of various spatial, environmental, and economic factors by using the analytic hierarchy process (AHP) and then uses this data to produce spatial map overlays that illustrate the distribution of potential deconstruction projects and the various factors. For those interviewed, Zehan found that environmental criteria are the most important, followed by resources, health effects on labor and surrounding residents, potential recyclable and renewable materials, and the commercial interests from deconstruction are the decisive factors in decision-making. Of course, the oft-overriding concern of costs cannot be ignored so the following chapter looked at that factor in greater detail.

Zhihan Fu’s “Chapter 5 - Factors Affecting the Cost of Deconstruction Projecting in the Pittsburgh Area,” found that the typical cost decision method for deconstruction is simply calculated by adding disposal cost, equipment cost, material cost, labor cost, and other minor costs such as permitting and testing. To improve the cost prediction of deconstruction, Zhihan proposes the use of cost prediction models based on machine learning such as Case-Based Reasoning (CBR) with weighted criteria from experts using Analytic Hierarchy Process (AHP). As Zhihan’s test case illustrates, these models could help decision-makers consider how to apply the weighting of these influencing factors to real deconstruction cases to improve deconstruction cost prediction models. It would also be helpful to explore ways emerging technologies could accurately quantify the potential material that could be recycled or reused from deconstructed projects as discussed in the final chapter.

In “Chapter 6 - Laser Scanning and BIM to Estimate Deconstruction Recovery Potential,” Weston Fortna shares his first experience using two FARO 3-D laser scanners and Revit to accurately capture the material type, quality, and quantity of an historic, but abandoned building in McKeesport, PA. Despite having a partially missing roof, previously undocumented additions, and other issues that would make a standard quantity take-off difficult, Wes was able to determine fairly accurately that the building contained approximately 606 tons of brick, 976 tons of concrete, and 139 tons of steel

which could be further evaluated using the images for potential salvage and recycling. Although this experience proved fruitful, it is recommended that the City of Pittsburgh officials also explore more cost-effective 3-D scanning and BIM technologies for deconstruction evaluations that could also improve on-site inspector/estimator time, accuracy, and safety.

Together these reports provide preliminary but valuable insights that could aid stakeholders in the City of Pittsburgh make better decisions informed by the goals of ecological preservation, social benefits for impacted by the proposed demonstration project, as well as economic feasibility through enhanced public conversation.

ACKNOWLEDGEMENTS

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CHAPTER 1 - BARRIERS TO DECONSTRUCTION & VISUALIZING BUILDING REMOVAL IN PITTSBURGH, PA

GRANT JOHNSON

ABSTRACT

Conventional building demolition produces more than a third of the waste in the United States, contributes to the release of particulates, and includes the use of heavy equipment (United States EPA, 2018). Deconstruction, the act of intentionally dismantling a building to allow for the recovery of material, can alleviate many of the issues caused by demolition as it reduces waste and minimizes exposure to the hazards of a typical building removal.

Many professionals within the AEC industry have expressed interest in deconstruction as a way of reducing waste and reclaiming materials. However, even with this focus, deconstruction has yet to become standard practice. This is due to the several barriers to its implementation. Although general research has been done in this area, this paper specifically investigates the barriers to deconstruction in Pittsburgh and the impacts of standard demolition.

Several methods were used to pursue this area of study. Geographic Information Systems (GIS) allowed for a visual representation of current potential deconstruction sites, as well as a recent history of razed buildings. The use of expert interviews supplemented a literature review focusing on the barriers to deconstruction, giving Pittsburgh-specific information on the industry trends and barriers. Rephotography, the method of comparing two pictures taken over time to show the effects of change, was used to show the impacts of typical building removal throughout the city.

In addition to the standard industry-wide barriers, major findings included the lack of proper deconstruction project management in Pittsburgh as well as the challenges associated with the current building stock. Finally, the ease of demolition allowed for properties to simply be removed and forgotten, leading to vacant lots throughout the city. Identifying these barriers is the first step in identifying solutions and implementing deconstruction correctly. Repurposing the salvaged material from deconstructed buildings within the community can address the vacant land left by demolition as we

INTRODUCTION

Impacts of Demolition

Construction demolition currently contributes more than a third of the waste generated in the United States every year, which equates to 230 million tons of building related waste (United States EPA). Across the world, it is predicted that more than 2.2 billion tons of construction and demolition waste will be generated annually starting in 2025. All this waste adds up, contributing to massive landfills and ensuring the material disposed has reached the end of its useful life.

Deconstruction as a Solution

When it comes to the end of a building's life cycle, the decision to demolish the building or deconstruct is an important one to make. *Demolition* refers to tearing down a building and disposing of the material whereas *deconstruction* refers to the systematic dismantling of a building to salvage material. Deconstructed material can be resold, reused or repurposed, stimulating the economy and prolonging the life of the building components. It works to combat the negative environmental effects of demolition by reducing the amount of waste added to landfills. However, the feasibility of deconstruction depends on the quality of the materials used and the current state of the building.

Besides its environmental benefits, deconstruction has social and economic benefits as well. Deconstruction often removes condemned properties in disadvantaged communities, which in turn can help increase the quality of the neighborhood. It also helps create jobs for people in the community, specifically work that would not necessarily require higher education. Finally, the resale of salvaged materials can generate substantial amounts of value.

Deconstruction in Pittsburgh

Deconstruction in Pittsburgh has had a relatively quiet presence, primarily lead by Construction Junction, a local material reuse store. Besides the sale of salvaged materials, Construction junction also has their own deconstruction team and can perform partial and full deconstructions on local building. Although Construction Junction is the most well-known deconstruction related business, there are several other local businesses that accept furnishings and other building components such as the Pittsburgh Furniture Company and SalvagedPGH (Locklin, 2018).

In April of 2021, Pittsburgh mayor Bill Peduto issued an executive order requiring the utilization of deconstruction techniques on all city-owned condemned properties

In April of 2021, Pittsburgh mayor Bill Peduto issued an executive order requiring the utilization of deconstruction techniques on all city-owned condemned properties (City of Pittsburgh, 2021). The primary drivers of this decision were the reduction of waste generated as well as the economic benefits created by deconstruction (City of Pittsburgh, 2021). Pittsburgh's past reliance on fossil fuels and heavy industry are still apparent today; attempting to combat the environmental impact of Pittsburgh's past is beneficial.

Although deconstruction is now required for city-owned buildings, it has not been mandated for any other projects. Demolition practices are still the primary removal method for buildings. Because of this, it has become necessary to determine what the biggest barriers are to switching from demolition to deconstruction in Pittsburgh. Although deconstruction is much better for the environment as well as the community, several factors come into play to deter building owners from selecting this method of building removal.

LITERATURE REVIEW

Previous research on deconstruction has provided some helpful background on the barriers to deconstruction in other locations as well as ways to spatially document the impact of demolition.

Barriers

One of the key issues of deconstruction is determining if there is a market for reclaimed materials. In the early 2000s Charles Kilbert found inconsistencies in the reuse market and the challenges faced by those trying to design buildings with salvaged material (Kilbert 2000). Abdol Chini and Ryan Buck identified some of the common building materials and construction techniques, as well as what the challenges surrounding them with the logistical challenges and increased cost being the biggest deterrents to deconstruction (Chini and Buck, 2014). Kambiz Rakshan recently provided a systematic literature review on deconstruction and analyzed the biggest barriers. Economics were again the largest barrier and are subdivided into cost for deconstruction as well as market availability. Regulatory issues were also found to have significant role (Rakshan, 2020).

As economic limitations are the biggest barrier to deconstruction, it would be helpful to quantify the added costs and explore the economic differences between demolition and deconstruction. Amol Taliya and Nasiru Dantata both review potential economic models for deconstruction (Dantata, et al. 2005; Taliya, et al. 2018). Comparing these to standard demolition methods would provide the cost differential of the actual work. It would also be very helpful to visualize the impact of demolition.

Visualizing Demolition

Combining all the previous information with GIS analysis on certain geographic traits (such as the locations of abandoned buildings), can give us an in-depth understanding of the barriers to deconstruction in Pittsburgh. David Wilson's study on abandoned buildings in Cleveland utilized GIS to identify common traits pertaining to the hundreds of abandoned buildings. The paper explained how the number of condemned buildings was increasing and commented on the common traits of neighborhoods with high concentrations of abandoned buildings. Low-income communities faced the brunt of this issue in Cleveland, but overtime the abandoned houses spread to adjacent communities as well (Wilson, 1994). Although not directly applicable to this study as this paper focused mainly on condemned buildings in Cleveland, seeing how they GIS work is applied to a deconstruction-related topic in a similar city provided helpful background.

Finally, case studies of Portland offered insights into how deconstruction has impacted the removal of buildings in their city and the regulations behind it. Portland created an ordinance in 2016 that specifically requires deconstruction for certain housing types. Permits for deconstruction have risen, and the number of demolition contractors that perform deconstruction jumped from two to seventeen (City of Portland, 2021).

The primary gap in available research is the lack of focus on the current building stock in Pittsburgh. Deconstruction is difficult for all building types as it requires extra planning and time, but even more difficult if there was never a plan to deconstruct. The condemned buildings in Pittsburgh were not designed for deconstruction, filled with permanent fasteners and difficult-to-remove adhesives. Most buildings were primarily constructed from structural brick, which is a defining characteristic of Pittsburgh houses (Conti, 2015). As there is permanent mortar between the bricks, it is clear the lack of designed-for-disassembly structures strongly impacts the efficiency of deconstruction.

PROBLEM STATEMENT & RESEARCH QUESTIONS

Although there is much available information on deconstruction as a topic and the barriers to its implementation, there are no specific studies on Pittsburgh. Looking at deconstruction specifically in this region is vastly different from other areas due to its history, buildings stock, and its overall openness to deconstruction. Finding out exactly how the typical barriers (cost, design challenges, market availability) come into play could potentially lead to solutions that could remove them.

Research Questions

1. How have demolition practices impacted the City of Pittsburgh?
2. What are the barriers to widespread adoption of deconstruction in Pittsburgh and how can they be removed?

METHODOLOGY

To investigate these questions, a combination of research methods including expert interviews, GIS, and rephotography provided an in-depth analysis on the barriers to deconstruction in Pittsburgh.

Expert Interviews

Using expert interviews as a research method allows one to properly question key informants or experts in a field to gain specific knowledge that might not be available in other locations. In this situation, an expert interview allows for Pittsburgh-specific information relevant to deconstruction. The two experts, Terry Wiles and Sarah Kinter, were interviewed for this study.

Terry Wiles, the Deconstruction Outreach Coordinator of Construction Junction, has seven years of experience in the world of building material reuse. Having spent all that time in Pittsburgh, he is well acquainted with deconstruction in this specific area. The goal of this interview was to determine market trends for deconstructed materials, Pittsburgh-specific barriers to deconstruction, and deconstruction costs. As Construction Junction also performs deconstruction services, his technical knowledge was also pursued.

Sarah Kinter works as the Acting Director of the Department of Permit, Licenses, and Inspections. She provided insight into Pittsburgh's condemned/razed building list and helped to determine the cost of building demolition. She also contributed to the barriers facing deconstruction from a policy lens, moving into the government's permitting aspects. Both these key informants have different areas of expertise but combine to give insight to the worlds of demolition and deconstruction in Pittsburgh.

Geographic Information Systems

GIS was specifically used to record the locations of all abandoned and condemned buildings in Pittsburgh, as well as all buildings removed in the last seven years. By geocoding the addresses of condemned buildings with Esri's ArcGIS, a map showing points for each one was created. This was overlaid with raster images to show density, as well as demographic data to demonstrate correlations.

Rephotography

Rephotography is the act of photographing the same site several times with a time lag between the pictures. It demonstrates the idea of then and now, showing how change has impacted a specific site. There are varying levels of rigor associated with rephotography. Some examples show the same object from the same viewpoint, while others undertake an in-depth study of the original image to ensure proper framing, angles, and lighting. In this instance, the primary goal was to investigate the impacts of modern demolition strategies; in-depth study of the original picture was not necessary. Using Google Maps' Street View option, images were taken of buildings before and after demolition. Toggling between past and current images showed how the land had changed over time and how demolition impacted the surrounding landscape.

FINDINGS

Deconstruction can positively impact the environment, promote a circular economy, and even create new job markets (Bertino 2021; Hines 2018). However, the widespread acceptance and implementation of deconstruction has yet to have materialized. Although several cities do encourage some degree of deconstruction or material reuse, the typical project tends to prioritize demolition. Discovering what those barriers are to deconstruction as an industry is the first step to learning what the barriers to deconstruction are particularly in Pittsburgh. First, however, it is necessary to understand the primary alternative to deconstruction, demolition, and the impact it has on the community.

Impact of Demolition on Pittsburgh

GIS allowed the study of each individual condemned building at a large, visual scale. The maps below show the geographical analysis of both condemned buildings and demolished buildings, with the latter being categorized by year. Demographic data is overlaid to show who is impacted the greatest by the condemned or demolished buildings. There are more than 1,700 condemned buildings shown and more than 680 that have been demolished, at roughly 100 structures a year.

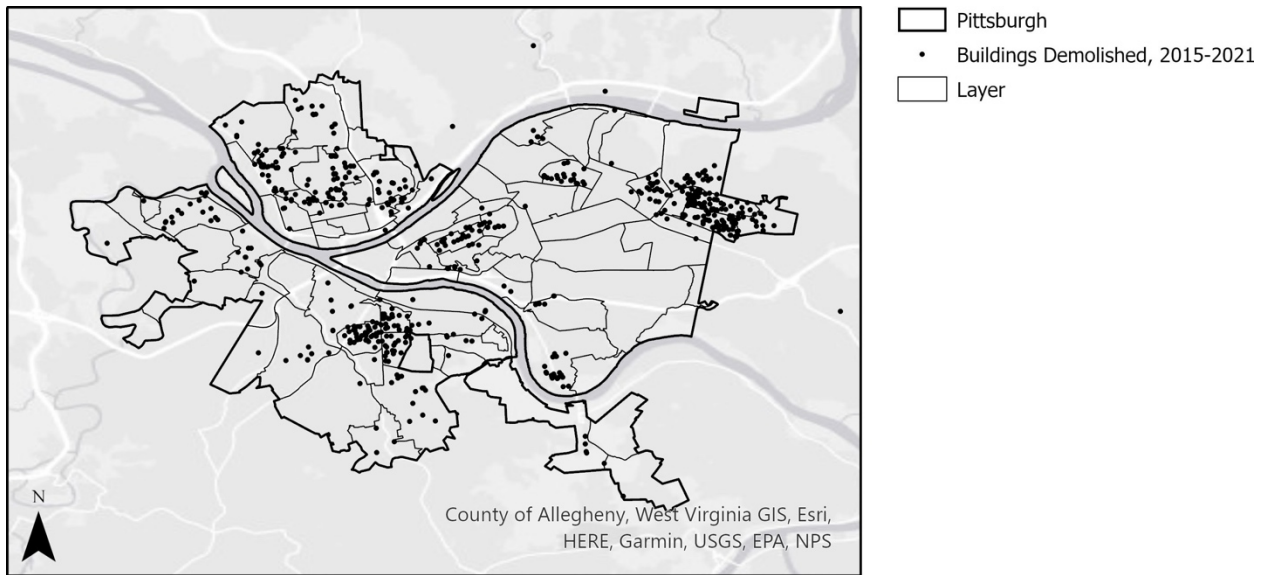


Figure 1.1: Demolished Properties in Pittsburgh 2015-2021

The above map shows all the buildings removed as of December 2021 since 2015. Although almost all neighborhoods have at least one removed property, it's clear that the majority of demolished buildings are concentrated in specific neighborhoods.

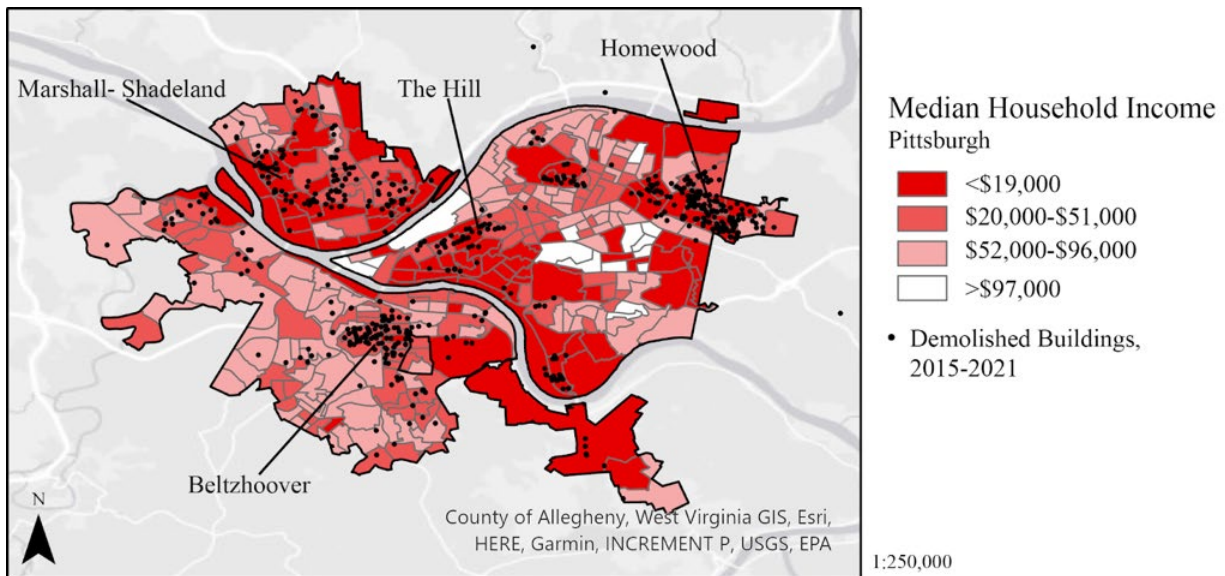


Figure 1.2: Median Household Income and Demolished Properties

Mapping demographic data on top of the existing building point data shows who is impacted by this building removal. The above map combines 2019 median household income with the building points, showing how primarily low-income areas face most of the building removal but not consistently across the city.

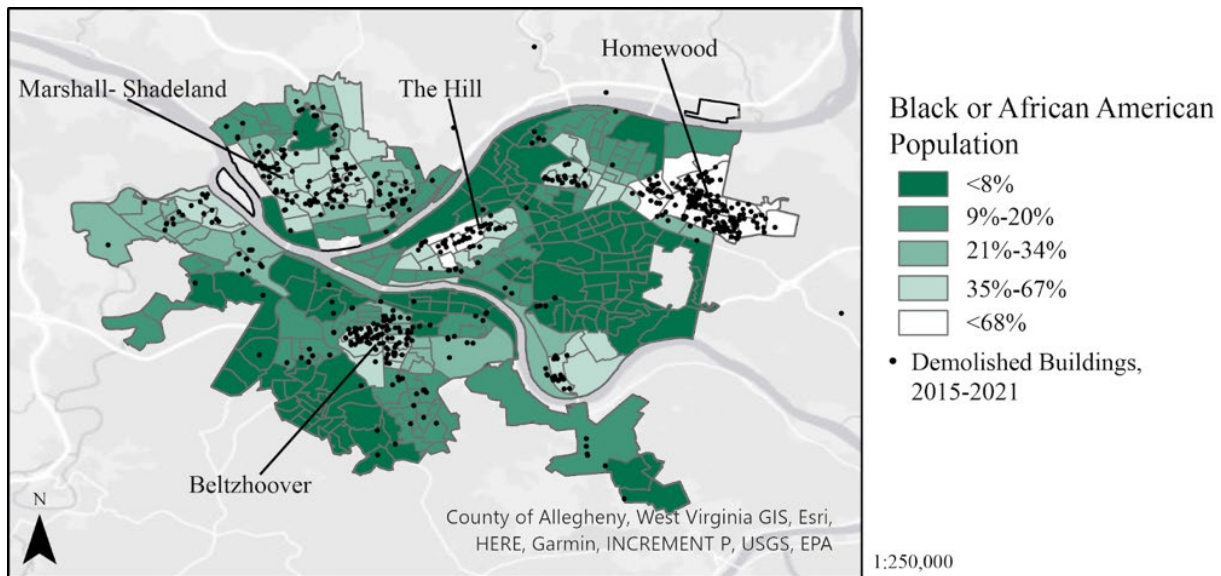


Figure 1.3: Black or African American and Demolished Properties

Adding racial data to the map allows for even deeper understanding. Majority-Black neighborhoods face almost all the building removal, where primarily white neighborhoods like Squirrel Hill face none.

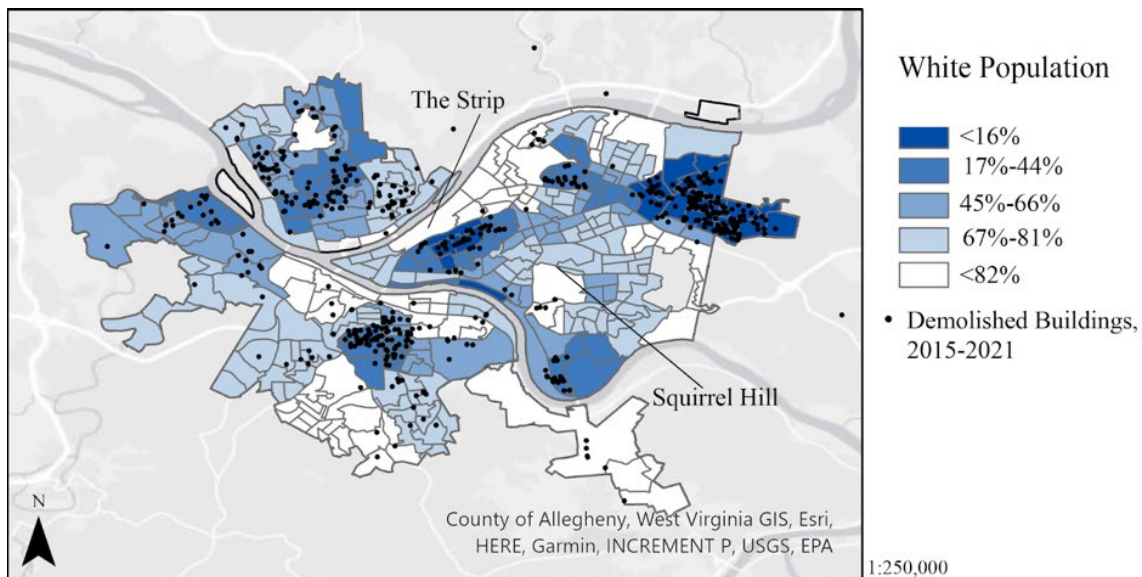


Figure 1.4: White Population and Demolished Properties

Utilizing these maps really shows us how specific groups of people are forced to handle the brunt of demolition within the city. Once the GIS data had been compiled, the next step was to investigate the actual buildings that had been demolished. Sarah Kinter explained the demolished buildings database, discussing many of the interesting facets of information presented (City of Pittsburgh, 2021). Based on this information, rephotography was applied to buildings categorized as “fire damaged” or in “imminent danger”. Based on Sarah’s expertise, it is likely that only the imminent danger buildings

would be slated for deconstruction based on the lack of salvageable materials created by a fire-ravaged building. However, these buildings are perfect examples of structures that are demolished quickly and left vacant.



Figure 1.5: Rephotography of 549 Winfield Street in 2014 (left) and 2021(right)



Figure 1.6: Rephotography of 713 Morgan Street in 2014 (left) and 2021 (right)



Figure 1.7: Rephotography of 626 Thompson Street in 2015 (left) and 2021 (right)

vacant land quickly becomes overgrown and filled with litter

The above images show the impacts of demolition on a neighborhood. Although the building has been removed, the vacant land quickly becomes overgrown and filled with litter. Salvaging the material from the structure and reusing it, either onsite or on a neighboring parcel of land, could help alleviate the issues with the empty lots.

Barriers to Deconstruction in Pittsburgh

Based on the review of several academic papers regarding deconstruction across the world and in the United States, there are several primary barriers to deconstruction. The largest of these barriers, as noted earlier, are the economic factors of deconstruction (Rakhshan, 2020). Economic factors can be broken down into cost, market availability, and time (Chini, 2014).

Although there is a possibility of deconstruction generating some capital due to the sale of recovered material, deconstruction costs currently are higher than demolition costs. This is the largest reason deconstruction is not currently used regularly (Chini, 2014). In Massachusetts, deconstruction costs average between 17% and 25% higher than demolition costs (Dantata, 2005). In Florida, deconstruction averaged 26% higher costs than demolition (Guy, 2003). These high costs can be attributed to higher disposal costs, transportation costs, and crew costs. Training laborers to perform deconstruction takes time, as does the actual building removal. Actual deconstruction time can be between three and five times longer than simply demolishing a structure (Dantata, 2005). This is due to increased sorting time or even a lack of available sorting area. As construction projects in the United States typically run long there is constant pressure to combat anything taking large amounts of time within the industry (Odeh, 2002).

The best way deconstruction combats these rising costs is through the resale of salvaged materials. In most situations, material can be donated to non-profit organizations resulting in a tax deduction. In some situations, a direct sale of salvaged goods can be completed. However, like the sale of any other good in the United States, there must be an available market and a demand for that good. When it comes to salvaged building material, that market is extremely unpredictable (Chini, 2014). This is due to the difficulty of designing to include reused material and the increasing skepticism of the market (Rameezdeen, 2016). Many times, the availability of materials is dependent on recent deconstruction projects which lead to limited materials. A consistent uncertainty prevents the consistent use of salvaged materials, leading to the whole concept of deconstruction being questioned.

After the economic barriers of deconstruction, the second biggest barrier is a technical one; current buildings are not meant for deconstruction, leading to logistical challenges, such as the removal of permanent fasteners and hazardous materials (Chini, 2014). If deconstruction is used on these buildings, which is usually the case, proper care must be given to each building component. If that care is not given, components face high risk of damage (Chini, 2014). This of course lowers the value of the salvaged component. In most deconstruction projects today, components already face wear from use (nail holes, erosion, termites, etc), so more physical damage lowers resale potential.

Although the economic and technical barriers are the largest to deconstruction, social and regulatory barriers come into play as well. From a social perspective, the perception that used material is dangerous or old prevents its widespread use, as well as some saying salvaged material looks worn out (Rakhshan, 2020). From a regulatory perspective, a lack of incentives available, as well as the need for special permits, slow down the process and deter building owners (Rakhshan, 2020).

Low cost of garbage disposal, additional costs, long periods of material exposure to the elements, and a general lack of deconstruction project management are large barriers to deconstruction in Pittsburgh

High costs, difficulties revolving around techniques, social implications, and regulatory barriers all impact deconstruction as an industry. In Pittsburgh, the barriers are relatively similar, as emphasized by several experts from the region. Terry Wiles emphasized how the low cost of garbage disposal in the region combined with the added costs associated with the time of deconstruction is a large barrier to deconstruction. There is no way to currently combat this, other than small scale deconstructions with the purpose of quickly removing salvageable material. Although this is more economical, it is less environmentally beneficial if salvageable material is left behind. With the Mayor's recent executive order, it is possible that this will change soon. Regardless, it is important to consider how building removal has been completed by the city in the past and how deconstruction could possibly make a difference.

Both interviewees commented on the existing building stock in Pittsburgh being partially responsible for the lack of deconstruction. Terry Wiles focused on the struggles of fully disassembling older buildings and the difficulty of obtaining materials of value that can offset the costs. Sarah Kinter expanded upon this, specifically from the point of view of the city's deconstruction program. Many of the structures on that list have been condemned for several years and have been abandoned long before that. Exposure to elements and a lack of proper care contributes to the building materials being unusable.

Finally, the last barrier to deconstruction in Pittsburgh is the lack of deconstruction project management on projects. Terry spoke about this in depth, commenting on the lack of proper planning that goes into Pittsburgh-based deconstruction projects. Deconstruction teams are usually an afterthought, added to projects that already have demolition planned. This severely limits the impact deconstruction has on a project and prevents the recapture of all the materials that could add value.

DISCUSSION

Information gained regarding the current state of demolition in Pittsburgh shows there is much room for improvement. Buildings are being removed constantly, primarily impacting areas with high concentrations of minoritized and disadvantaged residents. The abandoned lots left behind detract from a neighborhood's quality and are underutilized. In this situation, deconstruction might address some of those issues by reusing salvaged material in the same community it came from or even on the same land. This would address the environmental and social consequences created by demolition.

Identifying barriers preventing the implementation of deconstruction allows for future removal of those barriers. Due to the City's openness to deconstruction and its new initiative, it is possible deconstruction becomes a well-used building removal method. However, without proper measures to address its barriers, it is possible the initiative will not become widespread. The initiative only applies to City-owned buildings; without addressing the barriers preventing its use, it is unlikely private building owners will adopt the more expensive and time-consuming practice.

Moving forward, Designing for Deconstruction (DfD) is a relatively new design technique that allows buildings to be taken apart more easily. This can include design strategies like temporary fixtures, detachable components, and removable fasteners (such as bolts instead of welds/glues). Although DfD is helpful for the future, existing buildings have not been designed this way. Permanent fasteners and adhesives deconstruction, making the process much more time consuming.

Significance

Finding ways to implement deconstruction in a successful manner can lead to more sustainable building practices. Interviewing two key experts focused in on those barriers, and the GIS work specifically showed what areas of Pittsburgh are impacted the most by the current process of demolition. The rephotography worked to show the negative impacts of demolition visually, getting a glimpse into those communities. Learning how prevalent demolition is in Pittsburgh showed just how great of an impact deconstruction will have.

Limitations

The limitations of this study revolve around its focus of Pittsburgh and its lack of construction professionals involved in the discussion. Applying the information here to other cities could be challenging; the building stock in Pittsburgh, the geography, and the cities attitude towards deconstruction all separate it from other cities. However, it is possible that other cities similar in history and culture (Cleveland or Baltimore, for example), would have similar barriers. However, geographic building practices, such as Pittsburgh's focus on brick construction, do mean that there is potential for this study to have only a minor impact on them.

Finally, the interviews that took place were focused on both the policy side and the material reuse side of deconstruction. Although adequate for a small study, having more expert opinions would have strengthened the arguments made. Looking into local Pittsburgh architects and demolition contractors might have provided different information and other relevant perspectives.

Future Work

Future work would expand upon and address the limitations listed above. Expanding upon the interview process and speaking with other professionals would offer new perspectives on deconstruction. Demolition contractors and architects who currently utilize DfD would be considered relevant experts who could contribute to the study. Assuming the contractors do not currently offer deconstruction services, enquiring as to the reasoning behind that decision would be very helpful.

Due to time constraints, the use of GIS was relatively basic. Although it does an adequate job of demonstrating clusters of properties and identifying common spatial characteristics, fully pursuing the analytical side of GIS would be helpful. Density mapping of properties and proximity analysis of properties regarding each other would be interesting to pursue. Finally, using GIS to suggest new material reclamation sites would be very helpful. All three analytical GIS improvements would directly address

barriers to deconstruction, using GIS as a tool for overcoming the barriers instead of merely noting trends.

Finally, encouraging the use of salvaged materials in the same communities they were removed from would not only focus on a cradle-to-cradle practice but would solve issues created by empty land and trash filled lots. As Pittsburgh's deconstruction pilot program is recent, there is the ability to make changes to it based off our knowledge of the barriers. Besides incentives for community material reuse, addressing the cost barriers associated with deconstruction would be a necessary step moving forward. As Terry Wiles suggested, attempting to deconstruct all buildings equally is difficult; focusing on specific buildings constructed of valuable materials and applying partial deconstruction techniques will have the most practical impact.

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CHAPTER 2 - *JUST* DECONSTRUCTION: INVESTIGATING THE SOCIAL IMPACTS OF PITTSBURGH'S DECONSTRUCTION PILOT PROGRAM

ALYSSA MAYORGA

ABSTRACT

Currently, there are 1700 buildings across Pittsburgh that are condemned and about 20% or 340 are owned by the city (City of Pittsburgh 2021). In April of 2021, the City of Pittsburgh announced they will be initiating a Deconstruction Pilot Program under an executive order by Mayor Bill Peduto. Deconstruction is a systematic process of disassembling whole or parts of a structure to recover maximum economic and public good through reuse and recycling. A few cities across the US have already made great strides in implementing deconstruction as a tool with several studies providing informative background knowledge of deconstruction in other cities. However, these studies do not investigate the neighborhood politics specific to the Pittsburgh region. As the Pittsburgh Deconstruction Pilot Program commences, the properties chosen should be carefully selected to ensure social justice concerns are considered. This study uses expert interviews, GIS analysis, and rephotography to answer the following questions. "What are the current plans for the Pittsburgh Deconstruction Pilot Program?" And "What are the potential impacts of concentrating deconstruction within Pittsburgh's Avenues of Hope." I found that in order for a successful Pilot Program to begin in the Spring of 2022, the City of Pittsburgh needs to engage the Avenues of Hope leadership. I also found that the main motivator for engaging in a widespread deconstruction policy is for the environmental benefit, but a mass loss of property in a neighborhood can have significant impacts to the wellbeing of communities and businesses. This would especially impact minority and low-income communities. It is not a suitable solution in mass without a plan for the land following the practice. Recommendations include engaging the Avenues of Hope leadership once property selection begins in the pilot program as well as providing a dedicated plan that hosts a community benefit for each vacant lot following deconstruction.

INTRODUCTION

The US EPA recently found that construction and demolition debris rates have steadily increased each consecutive year, with the majority of debris occurring during demolition (EPA 2018). High levels of waste generation is a byproduct of urbanization, economic development, and population growth (Kaza 2018). To combat this ever-increasing waste generation, deconstruction has become a solution for many municipalities. Deconstruction is the process of taking apart a facility with the primary goal of preserving the value of all useful building materials (UFGS 2021). The adoption of deconstruction has been seen in many cities in the US and around the globe, and Pittsburgh has decided to adopt the practice through a pilot program.

In April of 2021, the City of Pittsburgh announced they will be initiating a Deconstruction Pilot Program under an executive order by Mayor Bill Peduto. It will follow 14 principles that cover a range of goals including policy parameters, a feasibility assessment, community engagement, and improving public health. The executive order states they would like to concentrate deconstruction in designated Avenues of Hope areas. The Avenues of Hope (AOH) are eight designated historically black business districts in the city. About 10% of the city-owned condemned properties are within the

The executive order concentrates deconstruction in designated Avenues of Hope (AOH) areas, eight designated historically black business districts in the city.

AOH areas. This initiative was introduced by Pittsburgh's Urban Redevelopment Authority in October 2020 as a result of international protests reacting to George Floyd's murder in the Summer of 2020 and the Black Neighborhoods Matter Movement. The AOH has very clear goals that align with social justice initiatives that include supporting Black-owned businesses, being centers of Black arts & culture, and advocating for healthy communities. This research analyzes the Pilot Program through the lens of social justice. With the expansion of the program, I will identify potential conditions, locations, and policies under which deconstruction should be implemented and when it should not. I will also consider the stakeholders necessary to ensure the success of this program once it expands.

LITERATURE REVIEW

A few cities across the US have already made great strides in implementing deconstruction as a tool. One city that has extensive experience in this is Baltimore, Maryland with the joint support of the USDA Forest Service and Humanim, a not-for-profit organization that aims to create economic opportunity and advocates for community empowerment (Urban Wood). Urban Wood has focused their deconstruction efforts on vacant, abandoned row homes in Baltimore (Urban Wood). The Green Pattern Book developed by the USDA provides eight green space uses for holding and reusing vacant land. A few of the identified green patterns include urban agriculture, green parking, and neighborhood parks (Jeff Carroll 2021). One of the major differences between Baltimore and Pittsburgh is that the bulk of Baltimore's deconstruction is out of local not-for-profit initiatives and Pittsburgh is establishing the program through policy.

Another city that has been successful in deconstruction is Seattle. The city has developed an extensive online Salvage Assessment Tool for owners that are interested in considering their property for deconstruction (City of Seattle 2021). They also track data through a Waste Diversion Report (City of Seattle 2021). This extensive method of

documentation of deconstruction provides in depth data on the success of the program. One of the major differences between Pittsburgh and Seattle is population growth. Seattle has been consistently growing in population while Pittsburgh has had a population decline.

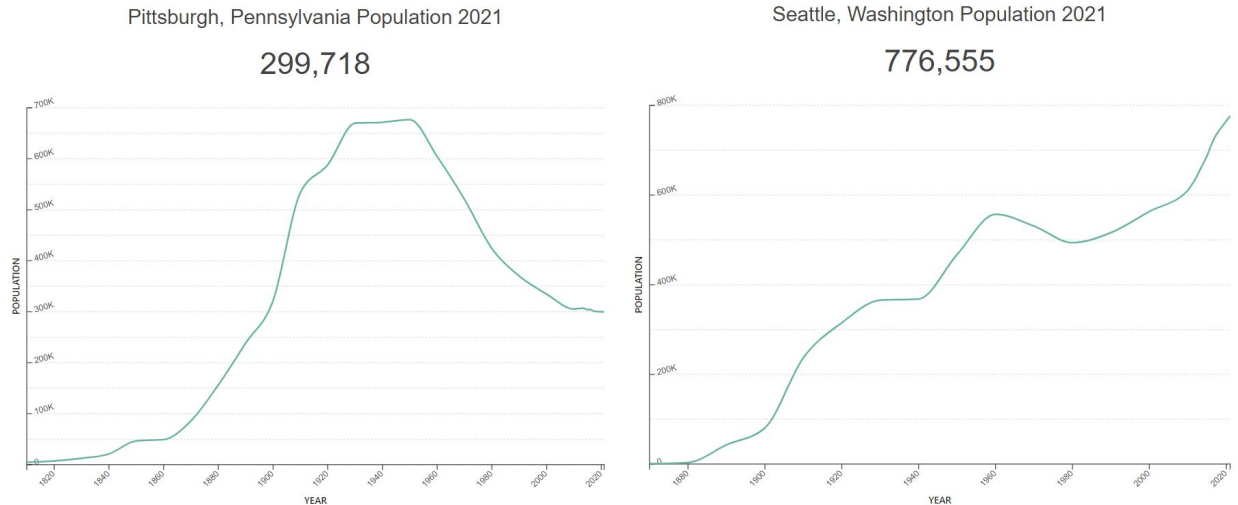


Figure 2.1: Pittsburgh v Seattle Population Growth. Source: World Population Review

Deconstruction can have a variety of benefits that span the social and the economical. Kibert’s case study research on deconstruction for public housing in Hartford, CT highlights social benefits like job training and employment. The Center for Economic Conversion estimated that there are ten resource recovery jobs for every one landfill job. Kibert’s research in other locations has had immense economic benefits. For example, his case study of EcoTimber in Berkeley, CA expected revenues from its reclaimed timber sales to climb from \$100,000 in 1999 to \$500,000 in 2000. The ReUse Center and Deconstruction Services in Minneapolis, MN expected more than \$800,000 in sales in 2000 from salvaged, reusable building materials (Kibert 2000). Andrew Downs analyzed the effects of demolition on the condition and assessed value of adjoining properties in Fort Wayne, Indiana. Though his research produced mixed results, his methodology outlined the decision process for what properties should and should not be demolished and also considers community participation (Downs 2010).

PROBLEM STATEMENT AND RESEARCH QUESTIONS

The literature provides research and documentation of other cities that have more robust deconstruction programs, but it is not specific to the unique conditions of Pittsburgh. Pittsburgh is a city made up of distinct neighborhood identities, politics, and demographics. Teixeira (2016) provided an informative study of several Pittsburgh neighborhoods surrounding the Avenues of Hope that mapped racial inequality by using youth perceptions to identify unequal exposure to neighborhood environmental hazards (Teixeira 2016). Some of the issues that Pittsburgh youth mentioned when discussing their neighborhoods included housing abandonment which they reported to be an eyesore, but also as locations to facilitate crime, delinquency, and negative health behaviors. Abandoned housing is discussed as a source of fear, anxiety, and sadness. “They also described the vacant lots as an environmental feature that cues negative emotion, promotes deleterious health behaviors, and stigmatizes their neighborhood” (Teixeira

2016). Pittsburgh's decision to focus the deconstruction efforts on those same neighborhoods could help address some of those concerns. However, more information and analysis is needed to help predict the potential positive and negative social impacts of the Deconstruction Pilot program. Therefore, this study helps identify beneficial policy recommendations as well as the roles and responsibilities of the partners the city has identified by asking the following research questions:

1. What are the current plans for the Pittsburgh Deconstruction Pilot Program?
2. What are the potential impacts of concentrating deconstruction within the Avenues of Hope?

METHODOLOGY

To answer these questions I utilized expert interviews to provide information and context for the current dialogue regarding the deconstruction program from the perspective of those building the program. They gave additional information about the status of the program that is not yet published. I then used this information in conjunction with case studies, GIS analysis, and rephotography to determine a list of recommendations that provide social benefit based on what has been done in other locations with more robust programs. The GIS analysis and rephotography provided a graphic illustrate the specific conditions in Pittsburgh. It also provided insight about the specific properties that are within the boundaries of the Avenues of Hope as an indicator of potential locations to be chosen for the pilot program.

Expert Interviews

I conducted expert interviews with representatives from the following organizations:

- Avenues of Hope/Urban Redevelopment Authority Management (URA)
 - Aster Teclay, Avenues of Hope Project Manager
 - Anonymous Officer
- City of Pittsburgh Deconstruction Working Group
 - Sarah Kinter, Director of Permits, Licenses, and Inspections (PLI)
 - Alicia Carberry, Operations Assistant
- Construction Junction
 - Terry Wiles, Outreach Coordinator

These interviews were designed to address the current stakeholder contribution to the Pittsburgh Deconstruction Pilot Program. The different working organizations are identified as significant stakeholders to the program, with varying perspectives. Each semi-structured interview was conducted via zoom and designed for a 30-minute conversation.



Figure 2.2: Interviewees

I asked the following questions during the interviews:

1. How long have you been involved in the deconstruction efforts in the City of Pittsburgh?
2. Have you participated in deconstruction efforts outside the City of Pittsburgh? If so, what did you notice in those other regions?
3. Of the Avenues of Hope properties, are there specific locations that you think the pilot program should start with? If so, why?
4. What social benefit do you think may come from this program?
5. What do you think is missing from the current research around deconstruction in Pittsburgh?
6. Do you have any concerns with the deconstruction program?
7. Do you have any personal motivations to support or denounce the expansion of the program?

GIS Analysis

The GIS Analysis builds on prior work done by city personnel that locates the distribution of condemned properties owned by the city in proximity to the Avenues of Hope (City of Pittsburgh). I used a publicly available spreadsheet to further symbolize the condemned properties based on ownership. I then analyzed the density of these properties in comparison to the identified Avenues of Hope. To demonstrate the patterns of areas with a high density of condemned properties, I analyzed Homewood as a sample neighborhood.

Rephotography

Rephotography is the act of repeat photography of the same site with a time lag between the two images. Google Maps Street View is the primary tool to show the most recent area to compare it to the first year that the area was photographed. After selecting “street view” on Google Maps, there is a drop-down option to toggle between different years. The earliest photos are from 2007. I used rephotography in a commercial area and a residential area in Homewood to highlight the streetscape change that occurs after the demolition of buildings versus commercial development. The commercial area is one of the Avenues of Hope corridors. This residential area is one of the streets with a high density of demolished buildings, identified from the publicly available Pittsburgh condemned properties list.

FINDINGS

The expert interviews provided context for how each stakeholder contributed to the development of the program and how they see it moving forward.

Sarah Kinter Interview

Before deconstruction or demolition takes place, a property is placed on the condemned properties list. According to the research done by my classmate, Grant Johnson, the average time spent on that list is about two years. Recently, the city has launched a website called Engage Pittsburgh that has a page dedicated to Condemned Property Demolition Engagement (City of Pittsburgh 2021a). This online tool explains the general tactics when dealing with condemned properties in the city. If owners are not responsive, PLI has the authority to demolish structures that may become “imminently dangerous,” meaning they have the potential for part of the structure to collapse causing harm to people, property, or obstruct the right of way.

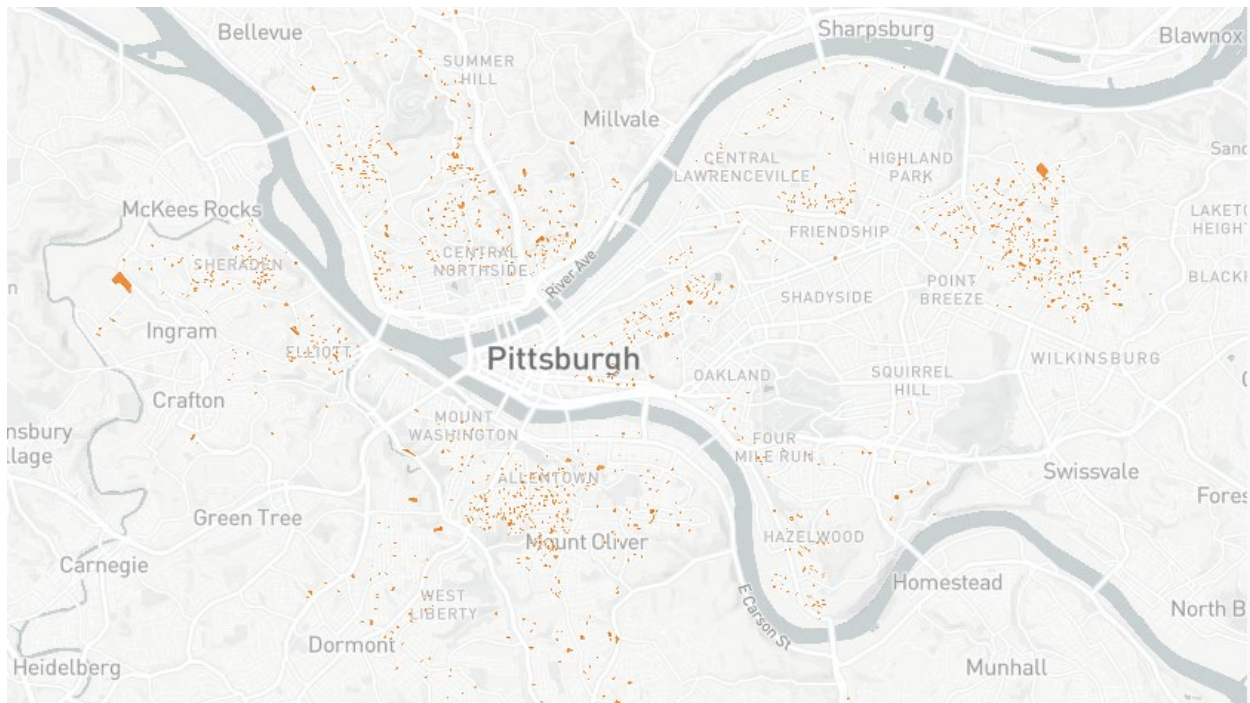


Figure 2.3: All Condemned Properties in Pittsburgh
(City of Pittsburgh 2021b)

Each condemned property is scored with a programmatic inspection tool. The scores range from 0-60, and are based on what the inspector can visibly see. 1500 of the 1900 condemned properties in Pittsburgh have been scored. Of those scored properties, they are averaging a score of 17, which means they are not considered dangerous structures and have potential for redevelopment. Demolition is usually considered for properties with score above 31, as identified by the PLI department. Hovering over the property provides information on the address, owner, parcel number, PLI score, and an option to leave feedback.

While Sarah Kinter’s focus is on PLI, there is another important sector, the Department of City Planning (DCP). When they score properties, they consider factors such as historical importance. My classmate, Rutuja Dhuru, provides a deep dive into this topic with her research on developing a more robust scoring tool to determine deconstruction eligibility.

One of the challenges with deconstruction has to do with procuring equipment. They must work with a list of verified vendors to work with them to provide labor. There is currently a list of approved contractors publicly available. Construction Junction is working as an advisor to these contractors and others interested in deconstruction.

Aster Teclay Interview

Aster Teclay is currently the Project Manager for Avenues of Hope, a new initiative started by the City of Pittsburgh’s Urban Redevelopment Agency (URA). As the Project Manager, she is responsible for coordinating and overseeing the moving parts of the new initiative, such as construction compliance.

The Avenues of Hope initiative was announced by the City of Pittsburgh via a press release in October 2020 as a result of the Black Neighborhoods Matter movement. This movement took place in Pittsburgh during the Summer of 2020 as the United States experienced mass protests calling out racial injustice. The initiative was pushed forward by multiple council members in the community. The majority of the program was modeled after the progress made within Center Avenue. In response, on June 28, 2021 Mayor Peduto announced his City Spending Plan and dedicated \$7 million to the seven Avenues of Hope regions (City of Pittsburgh). One of the goals of the program is to revitalize main streets, concerning blight and bringing buildings into highest and best use. She explains that Pittsburgh has very old infrastructure and it is costly to renovate which is why demolition is so widely used.

Aster expressed that deconstruction is an interesting concept and she has seen some instances in commercial buildings where valuable materials can be reused. However, she expressed concerns about its efficacy from a cost standpoint. Using available materials is attractive but when considering timelines, labor cost, storage cost, transportation cost, it is very layered.

When asked about the URA's involvement with the deconstruction pilot program taking place in the Avenues of Hope, Aster responded with "I have not heard about this program at all." The URA is an agency for the city but is separate from the city. The URA and the City coordinate on many programs but work as two different entities. Aster expressed concern with new programs being piloted in poor, black and brown neighborhoods. "It's not a playground, these are people's homes and lives and they should have access to the best resources." Through her career experience, she has seen that pilot programs may have noble intentions, but when they are being tested the outcome is not yet sound. She challenges leaders to expand their viewpoint of where these can be tested, maybe considering high end development. Another suggestion was to incorporate a structure that will have money on the backend if there needs to be a pivot.

Aster explained that one of the pillars of the Avenues of Hope are building wealth and entrepreneurship for current residents in the immediate area. The URA has lending products that provide capital for businesses that otherwise may not have access, especially for Minority or Women-Owned Business Enterprises (M/WBE). They also offer free technical assistance to provide holistic support for business owners.

Anonymous URA Officer Interview

The URA provides a variety of services for individuals considering entrepreneurship and specifically aids in providing start-up capital. Local individuals, minorities, and women are the main group of people requesting services, as it is difficult for this population to receive funding through traditional methods like bank loans.

Specific to the Avenues of Hope, they have recently created a tool for contractor lines of credit. This line of credit provides the opportunity for new contractors to have the resources to bid against bigger contractors. One barrier for entrepreneurs is obtaining the capital necessary to buy materials, equipment, and operation costs.

This officer expressed that they grew up in one of the Avenues of Hope (AOH) and they think it is a great opportunity for people to take pride in their neighborhoods. They

expressed that one of the focal points of AOH is commercial real estate. The executive director of the URA has been more involved in connecting the AOH with the City of Pittsburgh but it takes a while for that information to trickle down to people on the ground.

Alicia Carberry Interview

Alicia Carberry provided direct support for the chief operating office under Mayor Peduto's leadership. She took on a major role in pushing forth the deconstruction initiative internally. When developing the program, storytelling was an integral part of garnering support for deconstruction. This was necessary to combat any controversial sentiments and helped gain contractor support and community buy in. This was especially needed for the neighbors of abandoned and/or condemned properties, which mostly reside in neighborhoods with higher black populations and higher poverty rates. One element was highlighting the negative effect these properties have on public health. They specifically engaged people who called 311 often because they displayed interest in the wellbeing of their community. They also did some other forms of cold calling for a greater diversity of feedback. Some community responses to this have been comments like "where have you been," to express the dissatisfaction some Pittsburgh residents feel about the city taking care of surrounding communities.

When they began to build the deconstruction policy, they included input from eleven different city departments, who developed the 14 point framework as a city-led initiative. To support this policy, the 2022 operating budget has allocated \$250,000 to deconstruction.

When asked about the Avenues of Hope, Carberry mentions that they did not do enough to follow up with that team, because the strategy was unclear at the time. She stated, "The capacity of this needs to be built over time." The city has not yet identified a singular person to focus on this initiative. She expressed, the need to include more stakeholder participation.

Terry Wiles Interview

Terry Wiles is the Deconstruction Coordinator for Construction Junction and has been working in the industry for the past 10 years. His main role is to vet projects when people express interest in deconstruction by collecting data on the property like location, pictures, and the timeline for deconstruction. Once deconstruction takes place, he provides a detailed inventory of everything Construction Junction collected. Most deconstruction he has been involved in, has been partial, rather than full deconstruction. The goal is usually to strip out what can be saved based on value and its resell ability. Construction Junction specifically has an interest in brick because of its high reuse potential

As expressed by Alicia Carberry, Construction Junction has had many starts and stops with the city when they have tried to engage them with Deconstruction in the past. One of the barriers is that the city may have legal issues when they do not own a building, but have placed it on the condemned properties list. There is more opportunity and flexibility when a city owns a condemned building. The current relationship between the

City of Pittsburgh and Construction Junction, is that CJ has an agreement to train current demolition companies to train them on deconstruction and then provide an outlet for the material to go. To support this effort, they are looking at expanding their deconstruction team, especially with the Pilot Program. When looking at the future of the program, he expresses that the pilot program must be done in steps. In the next year, they are looking at deconstructing 20-30 buildings, or about 2 per month. The current stock of condemned buildings continues to grow because various properties have not yet been classified as condemned but are expected to be soon.

His personal perspective is that the environmental benefits such as decreasing carbon footprint is generally the most convincing, but deconstruction also has the potential to be an important employment generator. They currently work with the South Hilltop Men's Group and Trade Institute of Pittsburgh, which both work with people who have barriers to employment.

One concern Wiles expressed was with the changing administration since Ed Gainey will soon replace Bill Peduto as the new mayor of Pittsburgh. Therefore some city appointees that CJ had initially worked with including Alicia Carberry and those at PLI may be shifting and it may require a new process to get new appointees to buy into this program. He does believe deconstruction can play a role in stabilizing neighborhoods, which seems to be a goal of the new mayor of Pittsburgh.

Construction Junction has worked with the URA on other projects in the past. One example is when old schools are repurposed as multi-unit housing, which has an abundance of valuable material. In that case, CJ acted as a subcontractor. When asked about the Avenues of Hope, he mentions there is a lot of deconstruction potential here. The Homewood corridor is very close to Construction Junction. He also mentions that some structures do not need to be deconstructed. "It is a master planning question, because there are a lot of opportunities for property rehabilitation as well."

DISCUSSION

The experts interviewed each discussed their priorities in considering the Pittsburgh Deconstruction Pilot Program and the implications it may have given a social context. Aster Teclay and Alicia Carberry were both heavily leaning toward the social and economic benefit. Terry Wiles and Sarah Kinter leaned toward the environmental benefit while considering the social benefit. The anonymous URA officer leaned toward the economic benefit. These considerations all work together when discussing the context of Deconstruction as a program.

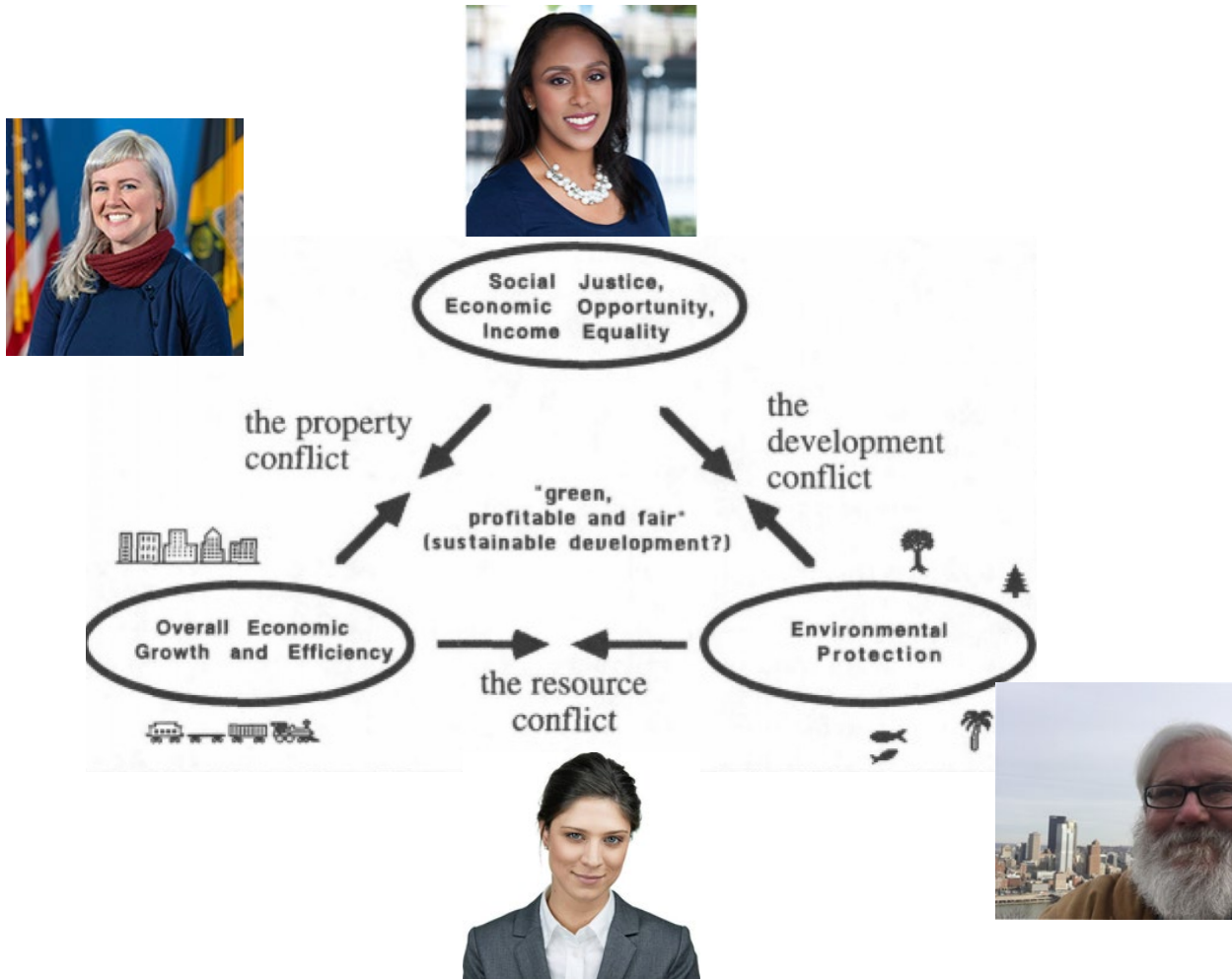


Figure 2.4: Interviewees' Interests Located on the Planner's Triangle (Campbell 2016)

As illustrated in Figure 2.4, Campbell developed The Planner's Triangle that describes the inherent conflicts that exist between social justice, overall economic growth, and environmental protection. Deconstruction can be viewed through each of these lenses and stakeholders may prioritize one over the other, as the interviewees exemplified. Regarding current political policy, economic growth and social justice are two major considerations. When considering sustainability and circular economy, environmental protection is a bigger consideration. Subsequently, the research focuses on the social benefit component, but acknowledges the economic and the environmental. In the following sections, I explain some potential affordances of deconstruction in the City of Pittsburgh through the each of the three lenses of sustainability.

Social Justice

Deconstruction provides a new labor market for the City of Pittsburgh to empower the local community.

INCREASED JOB CREATION THROUGH DECONSTRUCTION PATHWAY:



Figure 2.5: Job Creation

Deconstruction can create a full cycle career pipeline of skilled jobs that includes harvesting, separating, transporting, cleaning, and repurposing, and selling materials to build individual and community wealth.

Deconstruction has the ability to create a full cycle of job positions. In the actual stages of deconstruction, projects require additional labor on site as compared to demolition. The process of deconstruction takes much longer because there is more care and craft involved in taking apart architectural features, structural pieces, and concrete. Once all of the materials are taken apart, there needs to be a plan in place to divert materials, meaning separating them by category and transporting them to a new facility. This is another job. The materials then need to be cleaned and prepared for the new market. And the materials are then sent to a resale facility to be used again. All of these stages of deconstruction require hands and skill which is a new labor market for the city of Pittsburgh.

Construction Junction currently has partnerships with South Hilltop Men’s Group and the Trade Institute of Pittsburgh. South Hilltop Men’s Group is an “organization on a mission to reclaim their streets, restore community pride, and repair damage done by years of disinvestment and neglect” (New Sun Rising). They provide programming to encourage responsible entrepreneurship, workforce development, and case management support. The Trade Institute of Pittsburgh is a “non-profit building trade training provider dedicated to providing opportunities for individuals with barriers to employment (Trade

Institute of Pittsburgh).” TIP helps individuals gain entry into the construction industry. Both of these partnerships build up the opportunity for overlooked individuals to be gainfully employed through construction. The deconstruction progress opens up more opportunities for individuals.

To continue sustained job health, it is also important for these individuals to have access to expand their job opportunities beyond this immediate level. Once they have been trained in deconstruction, they should have a pathway to start their own business to have a better chance of sustained wealth. The URA has a variety of loan programs that offer business assistance to individuals. One specific loan is the URA Small Contractor Line of Credit Program. One of the qualifications for eligibility is work within one of the Avenues of Hope neighborhoods. Because condemned properties are concentrated in these locations, individuals have a high chance of working in these areas which also benefits community development.



Figure 2.6: Career Pipeline

Remove Blighted and Abandoned Nuisance Properties and Replace with Community Uses

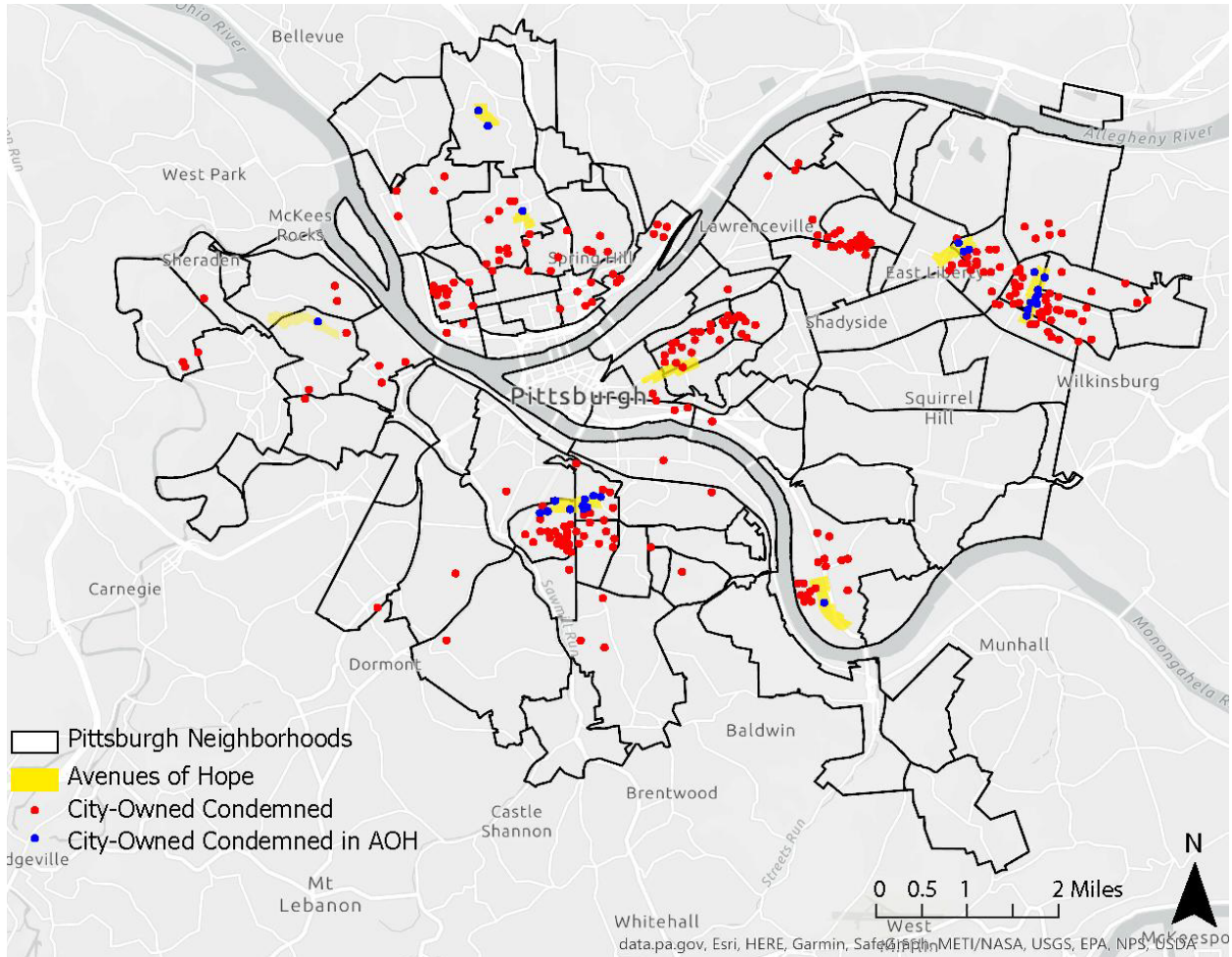


Figure 2.7: GIS Analysis of Condemned Properties within Avenues of Hope

Figure 2.7 indicates that city-owned condemned properties are scattered throughout the city with pockets of high density. The blue dots indicate the Avenues of Hope condemned properties which would be eligible to participate in the Deconstruction Pilot Program.



Figure 2.8: Idlewild St Rephotography 2007 v 2016

As you can see in Figure 2.8, the standard demolition policy removed three properties on the same block over a span of 10 years as a result of imminent danger. While removing abandoned and nuisance property is necessary, creating value for these spaces following demolition is important for community well-being. The potential negative impacts of missing properties includes overgrown land and decreased property value as noted by

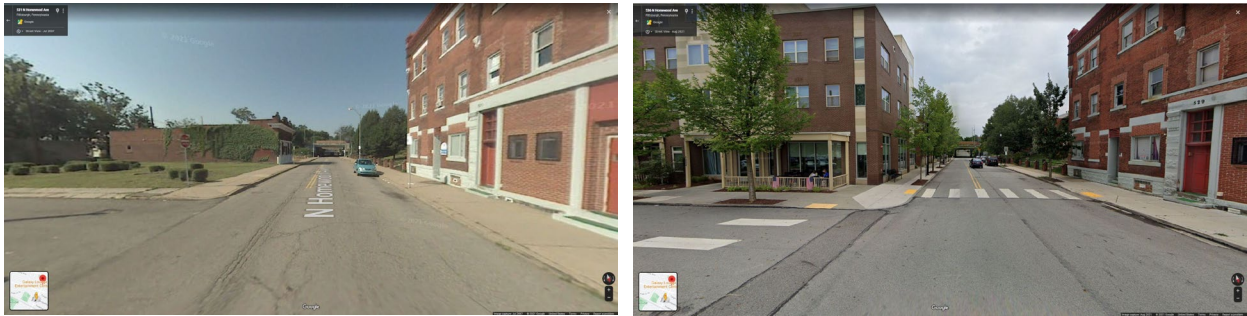


Figure 2.9: N Homewood Ave Rephotography 2007 v 2021

In contrast, the commercial corridor in Figure 2.9 has commercial development that improved the streetscape and crosswalks, as well as provided a senior center, neighborhood cafe, and office space.

Health concerns like poor air quality and asbestos are an environmental justice issue that disproportionately affects minority and low-income communities

Demolition can be a very violent process that releases dust and particles into the surrounding environment. Deconstruction instead takes more care when taking apart the structure and has a reduced chance of dangerous inhalation. Air quality is a major consideration for everyone's health, but especially children. When health issues persist among children it can affect their ability to participate in school and lead a long healthy life. Something to consider in Pittsburgh is the age of properties. Many old buildings contain asbestos and that can have a severe impact on lung condition. Considering these properties exist in mainly low-income and minority communities, air quality is a severe environmental justice issue. Data visualization on this issue can be found in Grant Johnson's research, "Identifying Barriers to Deconstruction in Pittsburgh."

Economic Efficiency

Deconstruction potentially provides the opportunity to stabilize communities but investment in development is essential to the goals of the Avenues of Hope.

If these neighborhoods had the opportunity to rebuild through investment in the communities, property values surrounding these areas could potentially rise. Deconstruction can contribute to stabilizing a community. Terry Wiles mentioned an example that described a street block where all of the homes had been kept up very well

except one. This home would be ideal for deconstruction because it would stabilize the neighborhood by removing that one property. It would also have a greater chance of investment for someone to rebuild on that land.

Another benefit of having more material on hand to resell to others is a cheaper cost of construction. Whether for small businesses or individual families, when they need material to do work, there is a greater supply. Brand new materials are often more expensive, and sometimes of lesser quality than older materials. Places like Construction Junction provide the opportunity to sell to people with limited resources and provide more affordable options. Construction Junction can also use the resale profit to continue to fund sustainable projects.

However, aside from deconstruction, true economic efficiency can be found in job creation through a more robust deconstruction pathway that includes labor on job sites, material diversion, material cleaning, and resale. In addition to this, deconstruction can provide new entrepreneurial opportunities for community wealth and advancement.

Environmental Protection

The City of Pittsburgh Deconstruction Principles include a commitment to connect improvised public health and wellbeing to use deconstruction instead of demolition.

The City of Pittsburgh has the responsibility to provide clean air and water and limit harmful exposure for their constituents. Many public health issues can come with living near condemned and possible demolished properties. Deconstruction is one effort that supports that role of the City.

It is also socially beneficial to keep materials out of landfills. By reducing the carbon footprint of the city as a whole, that benefits the health of communities.

Recommendations

The Pittsburgh Deconstruction Pilot should include some properties within and some outside the Avenues of Hope areas. Avenues of Hope leaders expressed concern that concentrated deconstruction in disinvested communities may lead to more social injustice, especially since they have not yet been engaged with this initiative.

The city should have a dedicated plan for each property post deconstruction. One of the results of a loss of properties over time is the “missing tooth” problem, when properties vanish, there should be a dedicated plan to replace that land with beneficial community use or affordable housing opportunities.

The city should engage leadership in the Avenues of Hope before any further decisions continue. Before choosing the specific properties to participate in the pilot, management and business owners within the Avenues of Hope should be consulted

Limitations & Future Work

One limitation of this study is the research scope. I only analyzed the Homewood neighborhood. There are seven Avenues of Hope designations in total and a more thorough analysis would look at the specific conditions of each of those neighborhoods.

Another limitation is that I was unable to include business leaders in the Avenues of Hope during my expert interviews. Their perspective would have provided insight into the potential effects this program on their businesses and communities.

A future topic to take forward given the above research is to identify specific properties to participate in the Deconstruction Pilot Program based on social benefit. This might include a more thorough analysis into the demographic properties of different Pittsburgh neighborhoods, as seen in Grant Johnson's research. This can also be taken a step further by utilizing tools created by Rutuja Dhuru and Zehan Zhang's research, in conjunction with this social analysis.

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CHAPTER 3 - DECONSTRUCTION ASSESSMENT FEASIBILITY AND TOOLKIT

RUTUJA DHURU

ABSTRACT

The building and construction industry consumes up to 40% of all raw materials extracted from the lithosphere and is accountable for almost 50% of the global greenhouse gas emissions (Bonoli, Zanni and Serrano-Bernardo 2021). Additionally, the industry also produces large amounts of waste during extraction, transformation, construction, and demolition. In the U.S. alone, construction and demolition (C&D) waste in 2015 amounted to 548 million tons. Buildings alone contributed approximately 30% or approximately 169 million tons, the majority of which waste is landfilled (U.S. Environmental Protection Agency 2018). Apart from waste generation, the process of demolition has harmful effects on the environment, as well as serious health and social issues (Chini and Bruening 2003). In contrast to demolition, *Deconstruction* - the disassembly of buildings to maximize the reuse and recycling of their materials safely and efficiently (U.S. Environmental Protection Agency 2021) - has social, environmental, and economic benefits (Chini and Bruening 2003).

According to research literature there are multiple barriers to deconstruction such as costing, time, and feasibility. These can be overcome if region specific deconstruction studies are conducted. The Pittsburgh Pilot Deconstruction program initiated on April 20, 2021 by Mayor Peduto, aims to test the potential of deconstruction of condemned, city owned properties to reduce blight in neighborhoods (City of Pittsburgh 2021). Currently 1700 properties in the city of Pittsburgh are classified as condemned by the city government's scoring systems.¹ While these systems help identify properties, they do not identify if the property is feasible for deconstruction.

Through case studies, literature research, and expert interviews, I created a multi-step process for identifying such properties. The process identifies properties through three levels. The first level assesses the building based on four questions - (1) Vacancy (2) Maintenance Costs (3) Structure Age and (4) Exterior Finish. Once this stage is cleared the property will go through two more levels of assessments. The second level will be on the condition of the property based on visual damage that can be observed. The third and final assessment will be through a detailed materials assessment. These three steps will determine the feasibility of the properties for deconstruction and whether it will be a salvage, partial, or full deconstruction. This system may also be

¹ Permits, Licensing and Inspections (PLI) and Department of City Planning (DCP) scoring systems.

helpful in assessing the feasibility and setting priorities for the other condemned properties throughout the city.

INTRODUCTION

Demolition can result in potentially harmful dust, empty unkempt plots of land, environment damage, social strife in the neighborhood, and serious health issues. At the end-of-life cycle of most buildings a significant portion of the materials are unrecoverable, such as poured-in-place concrete, gypsum board, and lead/asbestos-based materials. In the U.S. alone, construction and demolition (C&D) waste in 2015 amounted to 548 million tons, of which buildings alone contributed approximately 30% or approximately 169 million tons (U.S. Environmental Protection Agency 2018). The majority of this waste is landfilled. Apart from waste generation, the process of demolition has harmful effects on the environment, as well as serious health and social issues (Chini and Bruening 2003). In contrast to standard demolition, *deconstruction* - the disassembly of buildings to maximize the material reuse and recycling safely and efficiently (U.S. Environmental Protection Agency 2021) - has social, environmental, and economic benefits (Chini and Bruening 2003).

LITERATURE REVIEW

Deconstruction, although not new, is an unconventional method of removing buildings. As discussed in my classmate Grant Johnson's paper, deconstruction faces several barriers that hinder its widespread use. Several studies have concluded that deconstruction is more expensive and the process takes longer when compared to demolition, and there is insufficient data for assessment tools that easily synthesize available knowledge of deconstruction assessment, local materials, institutions and waste collection techniques and centers. Further buildings are inherently not designed to be deconstructed and there is a lack of deconstruction policy regulations.

Previously, deconstruction feasibility of buildings has been analyzed in one-off cases, either for a single structure, or for a particular region. While these studies have proved that deconstruction, in some cases, can be as economical as demolition, a set, careful process needs to be followed to achieve the result. According to Paruszkiewicz, Liu, and Hanes who studied the deconstruction of a building in Portland, OR - (1) deconstruction costs are higher due to labor intensity, (2) foundations cannot be removed, (3) it is cheaper when salvageable material can be transferred locally, (4) demolition is consistent, whereas deconstruction is not, and (5) deconstruction carried out by a nonprofit vs for profit partner might have differing costs. (Paruszkiewicz, et al. 2016).

Construction materials are either landfilled or downcycled when a building is conventionally demolished, losing its embodied carbon energy. However, salvaging and reusing building materials by deconstruction, can conserve the embodied environmental impacts of those materials

Construction materials are either landfilled or downcycled² when a building is conventionally demolished, losing its embodied carbon energy (Moore and Peterson 2011). However, salvaging and reusing building construction materials by deconstruction, can conserve the embodied environmental impacts of those materials (Moore and Peterson 2011). Sustainable architecture and built environments must consider the end-of-life cycles of materials (Avellaneda and Maccarini Vefago 2021). Practices and policy

² Downcycling is a process of recycling that degrades the quality of the material with each cycle. Plastics are commonly downcycled due to the complex chemical composition and imperfect sorting.

regulation that mandates conserving this embodied carbon energy of materials by the means of deconstruction needs to be established at a larger scale.

Deconstruction regulations across the US

Cities across the US have made successful attempts in mandating and/or regulating deconstruction within their jurisdiction. The City of Baltimore along with USDA Forest Services created the Baltimore Wood Project (USDA Forest Services n.d.). This project aims to tackle 4000 rowhouses which are condemned to be demolished in the next 4 years. Its benefits include reducing landfill waste, job creation, material reclamation, land and watershed restoration, and enabling community engagement. Similarly, the City of Seattle requires a Deconstruction and Salvage Assessment along with a Waste Diversion Report for demolition, for new construction and remodeling projects that include demolition and are greater than 750 square feet (Seattle Public Utilities n.d.). On October 31, 2016 Portland City Council adopted an ordinance that requires buildings built before 1940 or are designated as historic buildings and want a demolition permit to be fully deconstructed as opposed to mechanically demolished. By enforcing this, “Portland became the first city in the country to ensure materials are salvaged for reuse instead of being landfilled” (City of Portland 2016).

From these earlier precedents we can conclude that adopting deconstruction and moving away from demolition depends on timely and systemic feasibility assessments of structures, successful development of the local deconstruction industry and salvage markets, and the longer-term adoption of building methods that are compatible with deconstruction and reuse (Paruszkiewicz, et al. 2016). However, with the 2021 Pittsburgh Building Deconstruction Policy³ there is no widely-applicable and available assessment tool that can help ease this decision-making process.

Existing Building Deconstruction Assessment Tools

The purpose of a Building Deconstruction Assessment Tool is to facilitate the estimation of costs, revenue potential, and project management of the deconstruction of any structure. Twenty years ago Bradley Guy created a “Building Deconstruction Assessment Tool” (Guy, Building for Deconstruction Assessment Tool 2001) by analyzing the economic feasibility of deconstruction versus demolition of six single family residential buildings in Alachua County, Florida between 1999-2000. The research first defines net income for both deconstruction⁴ and demolition⁵. The tool has three steps (1) preliminary evaluation of the candidate building for its suitability for deconstruction, (2) calculating regulatory costs such as permitting and environmental assessments and cost of abatement of asbestos containing materials (ACM) or lead based paint if required, and (3) make a detailed assessment of the building-by-building component categories. From the assessment salvage percentage, salvage value, amount of disposal, and labor cost for removal can be calculated. The preliminary assessment section of the model uses a series of “indicators” of the building’s deconstructability, which are compiled into

³ City-led deconstruction policy designed to remediate blight in city neighborhoods while diverting building materials from landfills, advancing climate action goals, promoting equity, and creating job training opportunities, executed by Mayor Bill Peduto on April 20, 2021.

⁴ Net Income for deconstruction = (Price Paid by Owner + Salvage Value) - (Pre-Deconstruction + Deconstruction + Processing + (Transportation + Disposal))

⁵ Net Income for demolition = (Price Paid By Owner) - (Pre-Demolition + Demolition + (Transportation + Disposal))

a score. The limitation with this tool is its age, location specificity to Florida, and no known public use availability.

Similar attempts have been made by other city and federal governments to assess the deconstruction feasibility of structures. The City of Seattle's Deconstruction Estimator Tool is an Excel based calculator for estimating the total Reuse, Recycled, and Waste Diverted from any project. The tool first asks to list all the salvaged materials and divides them into three categories (reuse, recycle, waste) and then calculates their weight and overall percentage (City of Seattle 2021). It then directs the user to various recycling or C&D waste collection centers. The tool however fails to address deconstruction from an economic standpoint, which has proven to be a major motivator for people to adopt deconstruction practices.

Another attempt was made by the United States Environmental Protection Agency (EPA) with their Deconstruction: Rapid Assessment Tool for Structures (U.S Environmental Protection Agency 2021). This tool however works more like a checklist and fails to quantify/conclude any information provided by the user. Therefore, there is a lack of publicly available, economic feasibility-based deconstruction assessment tools in the market.

PROBLEM STATEMENT AND RESEARCH QUESTION

Like many cities in America's Rust Belt, Pittsburgh has experienced a sharp decline in population since the mid-20th century, resulting in vacant and abandoned properties across the city (Office of Policy Development and Research 2014). Currently there are over 1,700 buildings that are currently condemned as uninhabitable (City of Pittsburgh 2021). As of now there have been no formal deconstruction studies done within the city and no deconstruction data or guideline is available for people to follow which is specifically tailored to Pittsburgh. The recent Executive Order by Mayor Peduto issued on April 20, 2021, has the potential to drive this change.

Therefore, this study seeks to answer, "What do stakeholders want from deconstruction?" and *What kind of assessment tool would allow us to calculate the deconstruction feasibility of buildings in Pittsburgh?"*

METHODOLOGY

For this paper I first studied the condemned building scoring systems set up by the city government of Pittsburgh (City of Pittsburgh 2021). Second, I carried out expert interviews of various stakeholders with experience in deconstruction projects. My panel included Terry Wiles, Outreach Coordinator at Construction Junction (contractor's perspective); Corey Derico, Senior Construction Advisor at URA Pittsburgh (owner's perspective); and Bradley Guy, Co-Founder at Material Reuse (design/research perspective).

Through material research based on literature I identified several missing parameters in the city's system that are needed to carry out a thorough deconstruction feasibility assessment. Once these were identified, along with the recommendations from the interviews, I created a three-step assessment system, which once followed will inform the user whether the building can be feasibly deconstructed. Further to understand individual materials and their deconstructability, I framed questions such as

1. Can these materials be deconstructed?,
2. Can they be reused, recycled, or landfilled?, and
3. What is the equipment/crew type needed for the deconstruction of these materials.

FINDINGS

Stakeholders

While deconstruction simply means selective removal of building materials for reuse, its importance in the project varies from one stakeholder to another. From the three stakeholder groups interviewed, (1) government, (2) deconstruction contractors, and (3) owners/developers, all three had the goal of “environmental concern” as their primary concern. The owners/developers and government also shared the goal of “historical significance”, while the owners/developers and contractors shared the goal of economic gains through salvage value of material or tax credits. The government alone had a significant goal of “social justice” in order to opt for deconstruction.

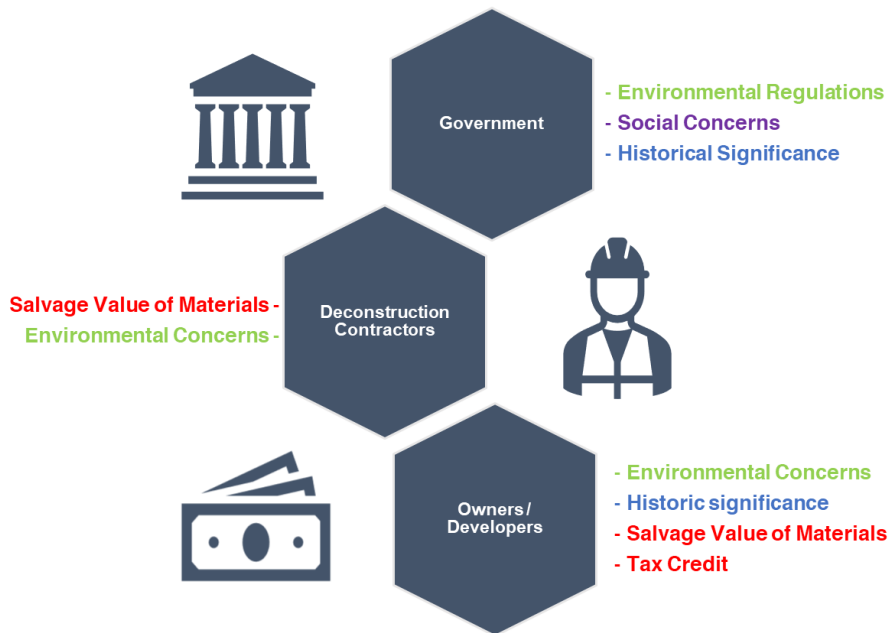


Figure 3.1: Stakeholder Goals for a Deconstruction Project

Assessment of Structures

For a building to be considered feasible for deconstruction, an assessment of set parameters must be fulfilled. From all the buildings in a city/neighborhood, it is difficult to assess every single one in detail to figure out if it is a suitable candidate for deconstruction. Generally, government organizations or deconstruction contractors have a list of parameters they use for rapid assessment of structures. While there is no deconstruction assessment in Pittsburgh, there are two organizations that identify properties for condemnation. The Permits, License, and Inspections (PLI) and Department of City Planning (DCP) have their own assessment system that rates properties and can have a vastly different score for the same property. According to the information on the EngagePGH webpage,

“PLI inspects all viewable elements of the structure to determine the extent of the damage, the potential for a collapse, the impact of the structure on adjacent structures, and impact to the public right of way. Structural elements would include the roof, walls, foundation, decorative features or overhanging elements, exterior stairs, decks, porches and balconies,

chimneys and towers, and other façade features. Inspectors review the structure at least annually to review how conditions have changed and assess for imminent danger accordingly.”

However, the DCP,

“examines the building or structure based on a series of factors related to its historical significance, its significance to the built environment, and its locational sustainability. These factors include: building age; building height; LNC or UNC zoning classification; presence on the National Register of Historic Places and the unofficial 1994 Pittsburgh Register of Historic Places; location outside of an environmentally sensitive area; and location on a street corner. Of these factors, a listing on the historic registers is given the highest priority for preservation” (City of Pittsburgh 2021).

As noted in Alyssa Mayorga’s Chapter of this report, “the scores range from 0-60, and are based on what the inspector can visibly see... Demolition is usually considered for properties with score above 31.” Figures 3.2 and 3.3 show two properties with varying scores by both organizations. In the first property the scores for both organizations are fairly close with a 3 and 7, but the second property indicates a radical difference between the PLI and DPC.

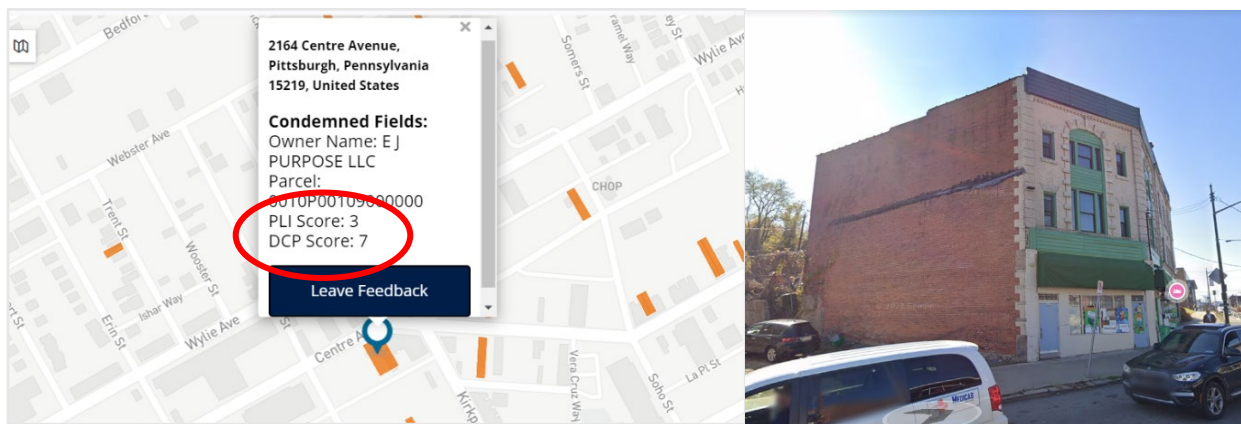


Figure 3.2: PLI and DCP scores of 2164 Center Avenue, Pittsburgh

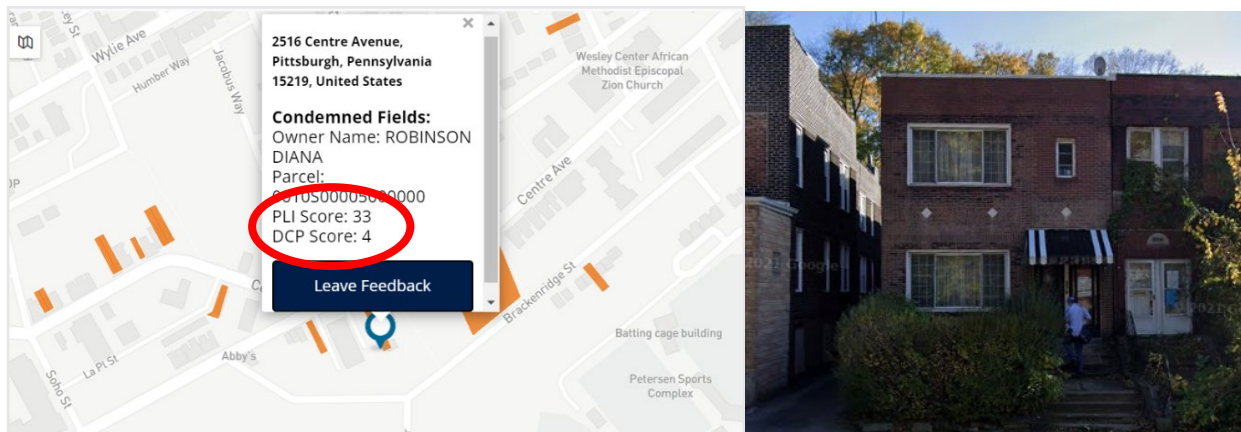


Figure 3.3: PLI and DCP scores of 2516 Center Avenue, Pittsburgh

Partial Versus Full Deconstruction

Full demolition or deconstruction are not the only two options for building removal. They are two ends of a spectrum which ranges from demolition to basic salvage/reuse to partial deconstruction, to full deconstruction. Demolition is when nearly all materials in a building are stripped down and sent to landfill with minimal scrap material, such as metals that can be recycled. Basic Salvage/Reuse occurs when building components and architectural elements are “soft stripped” such as appliances and cabinetry. When architectural elements like porches, columns, doors, windows, and wooden flooring are salvaged it is considered a Partial Deconstruction. Full Deconstruction is systemized dismantling of a building structure to maximize the recovery of components for reuse, restoration, and recycling.

One important deconstruction feasibility criterion highlighted by all the experts I interviewed was understanding what level of deconstruction a structure would benefit from. In many instances, if the structure is in a poor condition, a full deconstruction cannot be done in an economical manner. Decision makers need a system to identify the level of deconstruction that takes these parameters into consideration.

Assessment Parameters and Material Study

To understand where a structure lies on the demolition vs deconstruction scale an assessment system similar to the ones formulated by the DCP and PLI for condemned buildings needs to be formulated.

Vacancy, maintenance costs, ownership, exterior finish, structure age, exterior and interior assessments are a few parameters to consider when selecting a building for deconstruction. The greater the time a structure has been vacant, the more likely it is to be in a bad condition (Delta Institute 2019). Additionally, structures that are vacant and require excess maintenance are more likely to be in a bad condition (Delta Institute 2019). Structures built in the 1960s or later include more composite materials that are difficult to take apart and reuse, therefore buildings built during this time are generally a bad candidate for deconstruction (City of Portland 2016). Older homes are more likely to be made of better-quality materials as well. Brick is a robust material that can withstand weathering better when compared to wooden structures (Wiles 2021). If a structure has a brick exterior, especially one with lime mortar it can immediately be classified as a great candidate for deconstruction. Condition of a building is equally important. This can be assessed through a few simple interior and exterior assessments. Deconstruction requires ample surface space for staging and for the work crew to stay organized they require several workstations if a property lacks this, deconstruction would no longer be logistically feasible (Guy, Building for Deconstruction Assessment Tool 2001). If the property has extensive litter and/or hazardous waste, it might become labor intensive for cleaning the site and may impact the budget (Guy, Building for Deconstruction Assessment Tool 2001). The PLI assesses structure to understand if it is structurally sound, this is also important in the case of deconstruction as crews must be able to safely maneuver in the building. If the structure has had fire, water, roof damage or major cracking of brick, rotting wood, broken or missing window it might not be suitable for deconstruction. Damaged materials may not be market worthy, or the space might be unsafe for workers due to internal damage.

Materials and architectural components within the building while in good condition might not always be reusable. With the example of wood - timbers, large dimensional lumber, plywood, flooring, molding, and lumber longer than 6 ft is reusable. Whereas if these are untreated or unpainted, they can be unfit for reuse and thus can only be recycled (Avellaneda and Maccarini Vefago 2021). However, if they are pressure treated or rotting, they are beyond salvage and can only be landfilled at this stage.

Similarly, the material might possess environmental and health concerns if it is lead painted, low on structural integrity, contains asbestos, or vermiculite insulation.

All the materials and components possibly encountered in a project need to be categorized in a similar manner. The material chart shown below is a sample of certain materials and their categorization.

Table 3.1: Material Chart

	Reuse	Recycle	Landfill	Environmental & Health Concerns
Wood	Timbers, Large dimensional lumber, plywood, flooring, molding, lumber longer than 6 ft.	Unpainted and untreated wood unfit for reuse	painted, pressure-treated and rotting wood	Lead paint, structural integrity, asbestos, asbestos siding, vermiculite insulation
Windows	In good condition	Metal frames, screens, unpainted and untreated wood	Glass, painted items, damaged wood	Lead paint, asbestos in older glazing, energy inefficiency
Cabinets	Cabinets, hardware	Hardware, unpainted, unfinished wood	Unusable painted to finished wood	Lead paint, formaldehyde in particleboard or interior-grade plywood
Plumbing Products	Sinks, tubs, faucets	Metal pipes, toilets, inefficient plumbing features, faucets with lead content	PVC and other plastic pipe, toilet seats	Drinking water: lead content and asbestos wrap on pipes, in faucets, solder, and old galvanized pipe
Plaster and Gypsum wallboard	Wallboard in good condition	Clean wood lath, unpainted wallboard	Painted plaster or wallboard	Nuisance dust, lead paint or walls, possible asbestos in older wallboard, plaster, and popcorn ceilings
Electrical Products	Products in good working order	Metals (fixtures, conduits)	Ceramic and plastic parts	Frayed wires, possible asbestos insulation
Flooring	Clean carpet in good condition	Large quantities of ceramic tiles	Vinyl, stained carpet, broken tile	Asbestos content in tiles or sheet vinyl flooring, lead particles in dust and old carpet
Roofing	Sheathing in good condition, terra cotta or slate tiles	Metal materials, asphalt roofing, untreated cedar shingles	Treated cedar shingles	Possible asbestos content in roofing and vermiculite insulation

DISCUSSION

It appears that there is a lack of defined resources for assessing a structure for deconstruction, the findings of this study might contribute in part to develop a checklist and process for assessment and deconstruction of buildings. The stakeholders in a deconstruction project will have different goals depending on their organization. It also appears that today the need to deconstruction is primarily motivated by environmental causes and is independent of economic feasibility. However, if moving forward deconstruction becomes the new norm a feasibility assessment of factors is needed. The

publicly available assessments that do exist in Pittsburgh today are defined by the two governmental organization's interests and scope. Currently the city of Pittsburgh does not have a system of assessment for feasibility of deconstruction of structures. Additionally, not all buildings are feasible for deconstruction, some can only be demolished. Whether to deconstruct a building partially or fully depends on the decision makers involved. Building condition and its components and materials are crucial to understanding the deconstructability of the building.

Recommendations

A three-step assessment system can be proposed to understand the deconstruction potential of a building. This assessment will consider the findings presented before, which are gathered with the help of case studies and expert interviews. The 1700 buildings condemned by the city of Pittsburgh with the help of PLI and DCP scoring systems could be used as a starting point for the deconstruction assessment as these buildings are already condemned. The assessment system will have the following three steps (1) Preliminary Assessment (2) Conditions Assessment (3) Material Assessment as shown in Figure 3.4.

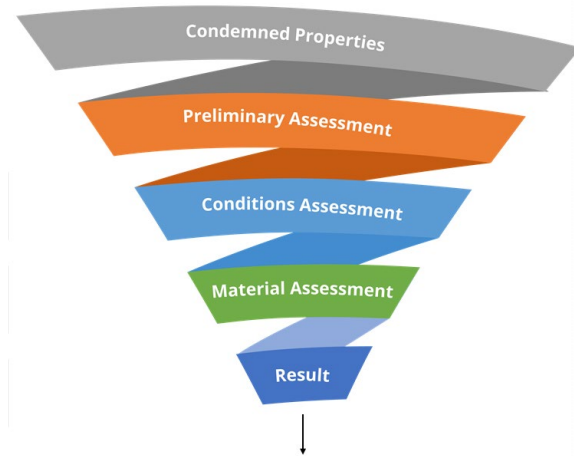


Figure 3.3: Assessment system for understanding the deconstruction feasibility of a structure.

Preliminary Assessment

For preliminary assessment, there are four parameters that can be taken into consideration which can categorize them into three sections - Best Condition, Ok Condition, and Bad Condition.

The parameters in this grading include: (1) vacancy - generally the greater number of years the structure has been vacant, the more likely it is to be in a bad condition. (2) maintenance costs - structures that are vacant and require excess maintenance are more likely to be in a bad condition, (3) structure age - structures built in the 1960s or later include more composite materials that are difficult to take apart and reuse, therefore buildings built during this time are generally bad candidates for deconstruction (4) brick structure - if the structure has a brick envelope it is more likely to be in a good condition. Once these parameters are rated and scaled to a range of 0-10 (0 being lowest and 10 being highest) we can assign each category equal weightage and normalize the total to scale of 10.

Based on the divisions in a normal bell curve distribution⁶ the results will then be divided into three categories (1) Good Condition (10-8.4); (2) Ok Condition (8.4 - 1.7); (3) Bad Condition - (1.6 - 0).

Table 3.2: Preliminary Assessment

Structure	Vacancy	Maintenance Costs	Year Built	Brick	Vacancy Score	Maintenance Cost Score	Age Score	Total	Category
A	4	\$500	1939	Yes	6	6	8	6.6	OK
B	5	\$300	1955	No	5	8	7	6.6	OK
C	5	\$5000	1973	No	1	2	1	1.5	BAD
D	1	\$50	1994	Yes	10	9.5	9	9.5	GOOD

Another parameter that can be included is the ownership of the property. If the property is owned by the city it has the authority to quickly demolish or deconstruct buildings whereas those properties that are privately owned must go through a longer review process.

Conditions Assessment

Once the candidates are selected through preliminary assessment, they can move forward to a conditions assessment. This is further divided into two categories - (1) exterior assessment - deals with site level parameters, and (2) interior assessment - which deals with structure level parameters. If a structure passes this assessment test, we can have the assurance that it is a good candidate for deconstruction.

Table 3.3: Conditions Assessment, Exteriors

Exteriors	
<i>Extensive litter and/or hazardous waste</i>	Removing waste is labor intensive and may impact the budget.
<i>Surface space for staging</i>	Space needed for work crew to stay organized and have several workstations
<i>Structurally Sound</i>	Crews must be able to safely maneuver in the building.

⁶A bell curve is a common type of distribution for a variable, also known as the normal distribution. <https://www.investopedia.com/terms/b/bell-curve.asp>

Table 3.4: Conditions Assessment, Interiors

Interiors	
Broken or missing windows, major cracking of brick, rotting wood	Possible weather damage due to this condition
Roof damage	Small hole/large hole/Portion of roof missing/Significant portion or entire roof missing
Fire / Water Damage	Damaged materials may not be market-worthy, and structures may be unsafe for workers.

Material Assessment

Once a structure passes the second test (conditions assessment test) we can move on to quantifying the structural and architectural components that can be salvaged. These will be listed by material type, size, and quantity. Later segregated into three categories depending on their use and condition. The three categories are - Reuse, Recycle, and Landfill as seen in Table 1. Further we can conduct an architectural features and furniture assessment. Here the items shown on the next page in Table 5 are quantified. These items are usually smaller and manageable in size, and easily removable when compared to the previous items. They can be easily sold off to either a reseller or a material reuse retailer like Construction Junction.

Table 3.5: Architectural features and furniture

Architectural Features and Furniture that can be salvaged

Item	Description	Quantity
Exterior		
Metal Gates and Fencing		
Exterior lighting fixtures/bollards		
Exterior Walkways		
Interior		
Fireplace		
Stair treads		
Stair railings		
Architectural woodwork - cornices		
Countertops		
Doors		
Door hardware		
Windows		
Glass blocks/glass walls		
Built-in cabinets		
Lighting fixtures		
Radiators		
Sanitary Fixtures		
Appliances		

Limitations

There are several limitations to this study due to the short research time frame. Firstly, the small sample size of professionals in the deconstruction industry that were interviewed can be increased to gather wider knowledge. Secondly a comparison of the recommended assessment system with the existing PLI and DCP scores is required to understand the differences and similarities in all three. Lastly, due to the short research

time frame for the project, the paper fails to account for a detailed study of previous deconstruction work done in Pittsburgh, along the same lines.

Future Work

After completing this study two directions for future research have been established. Firstly, a material study of deconstructed elements is very important. For instance, when wood or brick is deconstructed, we need to track the single material to a sorting facility through regrading and finally as use in a new location or structure is needed. This can tell us the future life of the material, embodied carbon and energy saved, and most importantly the effectiveness of deconstruction from a C&D waste mitigation perspective. Lastly, the use of the recommended assessment and process checklist on properties in Pittsburgh and further improving it to make it region specific is needed.

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CHAPTER 4 - ANALYSIS OF THE MAJOR INFLUENCING FACTORS ON DECONSTRUCTION IN PITTSBURGH THROUGH ANALYTICAL HIERARCHICAL PROCESS (AHP) AND GEOGRAPHIC INFORMATION SYSTEMS (GIS)

ZEHAN ZHANG

ABSTRACT

The City of Pittsburgh currently has 1,700 condemned properties and 340 are owned by the city. Typically, these properties are demolished within a few years, but the mayor recently announced a program to explore the possibility of deconstructing these properties instead to promote the reuse of construction materials.

Past research in several U.S. cities has highlighted a variety of criteria influencing the decision to stabilize, demolish, or deconstruct condemned properties. For example, construction materials and decision-making processes are locally and regionally specific. Therefore, it remains unclear which factors may be most impactful in Pittsburgh. This study uses expert interviews to establish the relative importance of various spatial, environmental, and economic factors by using the analytic hierarchy process (AHP). This data is then used to produce spatial map overlays that illustrate the distribution of potential deconstruction projects and the various factors. I found that environmental criteria are the most important, followed by resources, health effects on labor and surrounding residents, potential recyclable and renewable materials, and the commercial interests from deconstruction are the decisive factors in decision-making. For decision-makers in Pittsburgh, more attention should be paid to these factors as well as a variety of proactive considerations such as the design for deconstruction and deconstruction implementation.

INTRODUCTION

Research about reuse and recycling in construction has mainly focused on design and construction, but rarely mentions construction and demolition (C&D) waste. However, scarce resources (wood, metal, and natural gas) and components (piping, heating systems) are wasted during deconstruction over the life cycle of construction (Schultmann and Sunke 2007). In addition to the waste, Schultmann also summarized that the large amount of emissions and hazardous substances released to the environment during deconstruction is contrary to the aim of sustainability. In order to reduce waste and enhance sustainability in construction, decision-makers from different cities in the U.S. have made several regulations and programs to increase the use of deconstruction rather than demolition.⁷ However, these cities focus on deconstruction as it has a primary goal of preserving the value of all building materials, which contributes to sustainable development (US EPA 2018).

These programs discuss the important factors affecting deconstruction and provide a basis for the decision-making of local governments and other stakeholders. This leads to the question: How do the factors affecting deconstruction in these cities differ from Pittsburgh? Cases from Baltimore, Seattle, and San Antonio provide some valuable insight.

The following paragraphs are a brief overview of the deconstruction concerns of three U.S. cities. The City of Baltimore is concerned about the environmental impact and economic development of deconstruction (Hines 2021). The purpose of Baltimore's deconstruction is to stimulate the recovery of the urban wood processing industry and restore the economy. The factors that affect this purpose are as follows: 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. Different areas of the city have different ecological and social needs, so one set of solutions cannot be applied to all neighborhoods. Therefore, identifying potential vacant buildings and areas that would benefit the most from deconstructing buildings is a top priority for Baltimore.

The City of Seattle is concerned about the construction and demolition waste and biosafety disposal of hazardous asbestos and lead (City of Seattle 2021). Since the Seattle government is concerned about the above information, construction recycling and debris drop-off facilities, and groundwater resources are very important in Seattle. It is necessary to transport the debris of the project to the above-mentioned facilities to apply for the deconstruction or demolition 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. Therefore, Seattle's deconstruction projects are significantly affected by materials and various resources.

The City of San Antonio's deconstruction activities are based on environmental, economic, and social factors (City of San Antonio 2017). Deconstruction is environmentally affected by toxic dust, waste to landfills, 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 their deconstruction project can solve important environmental issues and achieve sustainable goals.

⁷ Demolition and deconstruction are both processes of removing structures, but deconstruction carefully takes the building apart piece by piece rather than using a wrecking ball and heavy equipment.

To summarize, the cases of the three cities proceed from their own needs and judge what they think are the most important factors for deconstruction. Figure 4.1 shows the different considerations of the three cities. The City of Seattle is concerned more about the environment and less about the economy, which is the opposite of the City of Baltimore. The City of San Antonio is the only city that thinks all three criteria (environment, economy, and society) are important. However, these factors are locally and regionally specific, making it difficult for us to copy the experience of one city to Pittsburgh. 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. Seattle and San Antonio have set up different potential deconstruction areas and properties based on the above information, which cannot be fully replicated to Pittsburgh. As the experience of other cities cannot be fully applied, it is necessary to find the most important factors affecting the deconstruction of Pittsburgh and use these factors to find feasible deconstruction projects.

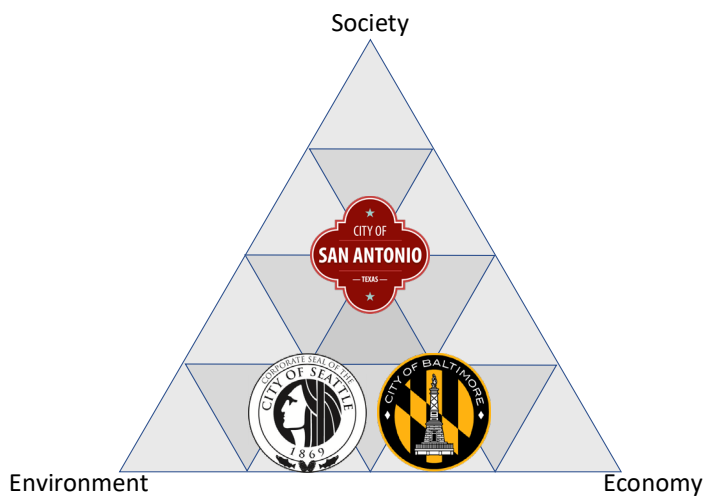


Figure 4.1: Important Factors on Deconstruction in Three Cities

The Mayor of Pittsburgh issued an executive order on April 20, 2021, “to develop a unified City-led deconstruction policy and establish a City-led pilot program utilizing deconstruction methods on City-owned condemned properties” (City of Pittsburgh 2021). Three hundred forty city-owned properties could be impacted in the short term, and eventually, more than 1,700 privately-owned condemned buildings could be deconstructed rather than demolished to produce usable materials. Considering the construction material recycling market in Pittsburgh and a large number of condemned buildings, the identification and application of deconstruction factors in the Pittsburgh area will provide administrative orders with opinions from different perspectives.

This paper obtained influencing factors through case studies and literature reviews and used the analytic hierarchy process to determine their relative importance. These data were then used to generate spatial map layers and used in decision-making. This paper clarified the influencing factors of deconstruction, and at the same time providing a new decision-making tool and process for decision-makers in Pittsburgh.

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, resource, economy, building type, society, and construction life cycle, etc.

Environment Criteria

The first section will discuss the contribution of deconstruction to the environment and green building. With the continuous extension of the concept of green building, researchers pay increasingly more attention to sustainable development. Deconstructing building materials instead of landfilling can produce considerable economic and environmental benefits, which reduces the consumption and transportation of landfills by at least 50% according to an agent-based model (Ding, Wang, and Zou 2016). Specifically, another major contribution of deconstruction is that it reduces the emissions of nitrous oxides (NO_x), sulfur dioxide (SO₂), carbon monoxide (CO), and particulate matter (PM) by 50%. Considering the environmental impact from the construction life cycle, Assefa concluded seven categories impacted by deconstruction and demolition (Assefa and Ambler 2017). Through life cycle analysis, in addition to Ozone Depletion Potential, deconstruction and demolition have a profound impact (reductions between 20% and 41%) on the following six categories: Eutrophication Potential, Smog Potential, Human Health Criteria, Acidification Potential, Global Warming Potential, and Fossil Fuel Consumption.

In terms of green recycling and sustainable development, the concept of "cradle to cradle" material recycling developed by McDonough and Bruangart further clarifies the beneficial effects of destructed materials on construction activities (McDonough and Braungart 2010). Even though deconstruction will consume more cost and time compared to demolition, it is much more environmentally friendly. Taking steel as an example, environmental pollution will be reduced by 96% through deconstruction compared with the use of new steel (Cheshire 2019).

In general, we can find the main factors of environmental impact from the above research are air pollution, human health criteria, fossil fuel consumption, resilience, and global warming.

Resource Criteria

The following paragraphs summarize the relationship between deconstruction and different resources. 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 and Ambler 2017). By comparing the meaning of the concepts of "recycling", "reuse", and "deconstruction", Schultmann considered the similarities between the construction industry and the manufacturing industry. When considering the building deconstruction plan, he focuses on the repair, renovation, dismantling, and reuse of materials (Schultmann and Sunke 2007). 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 and Sunke 2007).

For example, concrete and wood are two kinds of significant materials that can be recycled from deconstruction. The US EPA Office of Resource Conservation and Recovery paid more attention to different material types while considering secondary uses and drew the conclusion that the most construction-related debris is from concrete (US EPA 2018). However, Höglmeier conducted a similar case study of Germany and found

that wood is the most effective material for deconstruction (Höglmeier 2017). When making a deconstruction decision, in addition

to whether it is recyclable, another equally important consideration is whether the material contains toxicity (Zoghi et al. 2021).

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 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 and Okudan 2021).

Höglmeier studies the material life cycle and focuses on the deconstruction process after the material is reused (Höglmeier 2017). He considers the possibility that materials eventually become biochemical products and energy carriers and found that the focus on particle-based 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, Wang, and Zou 2016). To summarize, the material involved in deconstruction is the most important factor among all resources. In addition to this, other resources for deconstructing utilization should also be considered.

Economy Criteria

This section introduces the literature on the relationship between economic development and deconstruction. Elefante looks from an economic point of view, focusing on the secondary space planning and green performance of built buildings (Elefante 2007). Kaza 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 (Kaza Silpa 2018). 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 construction and demolition 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 return, while the above-mentioned literature expounds on the relationship between them from the three aspects of regional economic development, cost, and interest.

Building Type Criteria

This section presents literature about the deconstruction possibility of different building types. When considering the recycling of building materials, Ding found that building type will affect the quantity and quality of recycled materials. In his quantitative research, Ding found that the value of recyclable materials in residential buildings is about 1.45 T/m² (-0.14 T/ft²), while the value of recyclable materials in

commercial buildings is about 1.38 T/m² (-0.13 T/ft²) (Ding, Wang, and Zou 2016). In another study, Ding found that attractions have an important influence on the decision-making of waste management and related projects. In his analytic hierarchy process, whether buildings belong to attractions is the most important factor in addition to environmental factors and geographic factors (Ding et al. 2018).

Generally, the above three types of buildings: residential, commercial buildings, and attractions are the most likely to be deconstructed. Other types of buildings, such as historical buildings need heritage protection and restoration instead of deconstruction. Even though the restoration of these buildings also focuses on the building materials and the maintenance of the meaning of the building itself (Bie Plevoets and Cleempoel 2013). When trying to repair historical buildings, other factors such as climate change and historical development must also be considered (Elefante 2007). Hence, these buildings will not be considered in deconstruction projects.

Society Criteria

One concrete manifestation of the potential social impacts of deconstruction in the built environment is the concept of Open Building. John Habraken created Open Building to give residents more agency over their multi-family environments by dividing construction activities into three parts: basic construction, interior construction, and furniture fixtures (Kendall 1999). This method reduces waste, is well-aligned with deconstruction, and has achieved success in the Netherlands and Japan. 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 and Zuberi 2016). As discussed in greater detail in Alyssa Mayorga's paper, the targeted locations for the mayor's deconstruction pilot project are located in or near the city's Avenues of Hope, several majority black-owned business districts (City of Pittsburgh 2021).

To summarize, this section focuses on the social factors which are discussed in greater detail in Alyssa Mayorga's paper. However, these factors are not concluded in this paper as lack of systematic classification. Detailed information is discussed in the Weighted Overlay Analysis section.

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's is needed. The factors used in this paper are shown in [Figure 4.2](#). These factors are classified into four criteria and are detailed discussed in Analytic Hierarchy Process section.

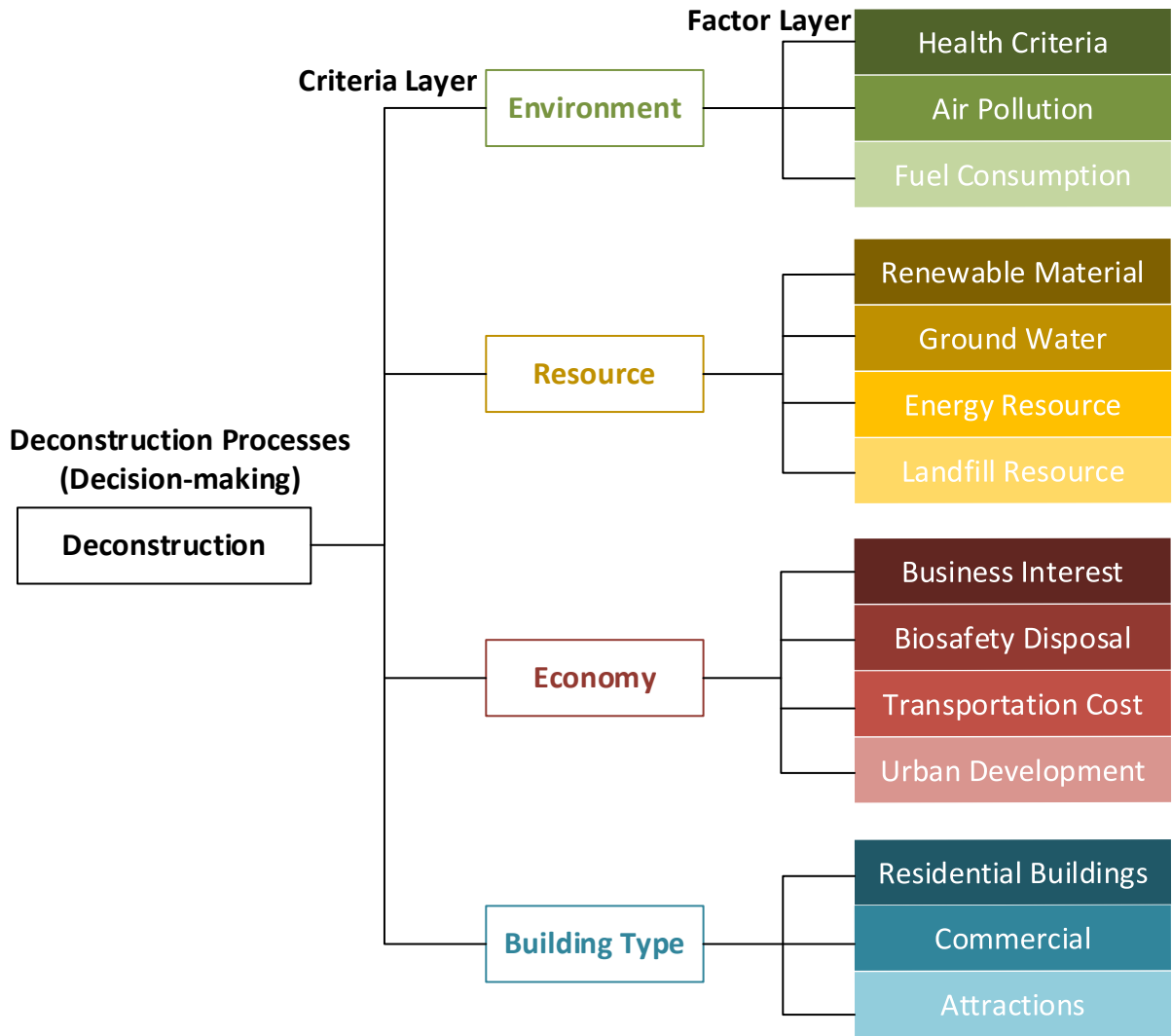


Figure 4.2: Factors Used for AHP

PROBLEM STATEMENT AND RESEARCH QUESTIONS

Therefore, the following gaps remain. There is no research on integrating the above categories from the perspective of decision-makers. Researchers tend to study one or two categories of factors, but for decision-makers, more factors need to be considered simultaneously.

The second gap lies in the fact that the literature provides cases from different areas of the U.S. and countries such as Germany, Japan, and China, but there is a lack of research on Pittsburgh. Therefore, the factors affecting the deconstruction of Pittsburgh are still unknown.

The third gap is the lack of practical application scenarios in the discussion of influencing factors. The discussion of deconstruction influencing factors stops at case application and modeling. Previous studies have not considered whether the existing condemned buildings in Pittsburgh meet these factors or which other potential areas may have deconstruction projects? However, in Ding's study of landfill site selection, the

importance of influencing factors is used as a reference for site selection, which provides research ideas for solving the above problems (Ding et al. 2018).

In order to fill the above research gaps, this study explores the following questions:

- What are the most important influencing factors related to deconstruction in Pittsburgh?
- What areas should the city target for the deconstruction pilot program based on the most important influencing factors related to deconstruction in Pittsburgh?

METHODOLOGY

Two research methods were used to answer the two research questions. The first question required expert opinions involved in policy decisions of deconstruction projects in Pittsburgh. Three experts identified the relative importance of factors through a list compiled from the literature research and ranked the factors accordingly using the Analytic Hierarchy Process (AHP) method. The second problem required conversion of the weighted factors into spatial information to identify potential deconstruction areas through geospatial information systems (GIS), specifically ArcGIS Pro's Weighted Overlay. These two methods were used as a test. This paper used this initial experiment to demonstrate the advantages of AHP as a decision-making method and further applied the conclusion of AHP through GIS analysis. The relationship between the two methods and more detail about each method are discussed below.

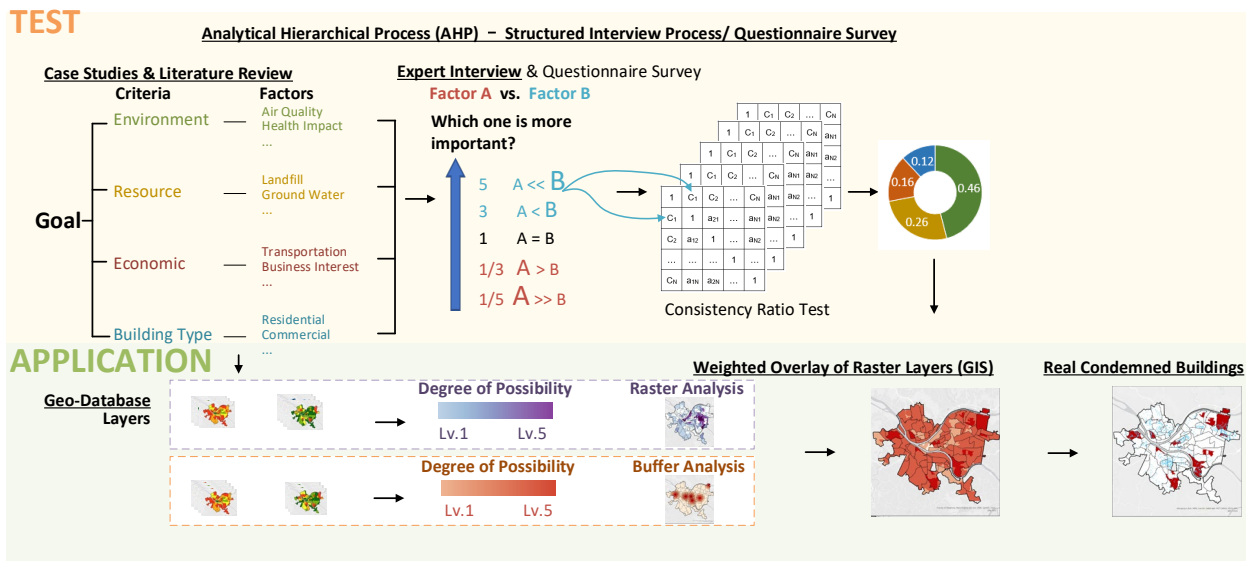


Figure 4.3: Methodology Relationships

Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is used to integrate the opinions of experts and distinguish the importance of each opinion (Ding et al. 2018). AHP is a mathematical method for decision-making using effective weighting coefficients and considers the inaccuracy in the expert decision-making process (Koc and Okudan 2021). The steps to solve the first question are as below.

Step 1. Clarify the scope of experts. The knowledge of experts is the foundational layer and main determinant of AHP analysis. Therefore, we need to select qualified experts. Experts in the construction industry, academia, and politics who have

participated in demolition or deconstruction projects, have research experience or have management experience are our 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, Tativa optimized the impact of the number of experts. He demonstrated that 11 experts could reach extremely reliable conclusions, and three experts are sufficient to reach preliminary conclusions (Tatiya et al. 2018). While ensuring the diversity of expert backgrounds, this research selected three experts for AHP research. Their specific information is as follows.

Table 4.1: Basic Information of Experts

	Expert1	Expert2	Expert3
Name	Alicia Carberry	Terry Wiles	Sarah Kinter
Title	Recycling Supervisor & Operations Assistant	Outreach Coordinator	Director of PLI
Organization	City of Pittsburgh	Construction Junction	City of Pittsburgh
Focus Area	Health Criteria & Economic Criteria & Career Opportunities	Recyclable Materials	Environment Criteria

Alicia Carberry is the recycling supervisor of the City of Pittsburgh, and she is committed to expanding the recycling of building materials and reducing the waste in the whole construction process. Prior to this, she was the Operations Assistant and promoted deconstruction projects within the government. When constructing the deconstruction plan, she referred to the experience of different cities and suggestions from Construction Junction. Terry Wiles is the outreach coordinator at Construction Junction, a local reseller of salvaged building components. He has participated in many deconstruction projects and provided review work and recyclable building materials and components lists from Construction Junction for these projects. Sarah Kinter is the director of Permits License and Inspection (PLI) at the City of Pittsburgh. She reviewed condemned properties in Pittsburgh and analyzed their potential for deconstruction based on the degree of structural danger. Based on their extensive experience in participating in deconstruction projects and their wealth of expertise, they were selected as experts for AHP analysis.

Step 2. AHP Model Determination. The AHP model of this study was based on literature analysis 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. The model is shown in Figure 4.2.

The following paragraphs show the detailed information for each criterion. For deconstruction activities, this research considered the four categories of environment, resource, economy, and building type, but not the two categories of society and life cycle. The social impact of Pittsburgh’s Deconstruction Pilot Program was very well discussed in Alyssa Mayorga’s paper about just deconstruction. This paper didn’t consider society because of the lack of a systematic discussion of social influences and a summary of social factors that affect deconstruction. The analysis based on the life cycle demonstrates the importance of deconstruction, but the impact on deconstruction itself

is not obvious. Therefore, this paper didn't separately consider the impact of the life cycle on deconstruction.

Environment criterion contains three factors: fossil fuel consumption during deconstruction, health criteria for both the laborers and residents, and air pollution which summarized the emission of nitrous oxides (NO_x), sulfur dioxide (SO₂), carbon monoxide (CO), and particulate matter (PM). Resources criterion contains four factors: landfill area resources, groundwater resources, petroleum and gas energy resources, and renewable and recyclable materials obtained from the project. Economic criterion contains four factors: urban development for each neighborhood indicating the poverty level and housing conditions, transportation cost, biosafety disposal cost for hazardous materials and business interest. The building type criterion contains three factors: residential buildings, commercial buildings, and attractions.

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 $\frac{1}{5}$ to 5. The weight relationships represented by different numbers are as follows. This paper used a semi-structured interview through Zoom with clarifying questions and comments from experts to ensure that the questions were clearly understood. The sample questions used in this paper are listed in the appendix.

Table 4.2: 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
* 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. Under decision science, most decisions are made through the subjective opinions of stakeholders. Therefore, it is necessary for AHP to clarify the reliability of the subjective opinions of experts. The consensus ratio (CR) of each expert to the factors in each criterion must be less than 0.1, otherwise it is not considered. A CR value greater than 0.1 means that the expert has a contradiction in the pairwise comparison of certain factors. For example, the expert believes that factor A is more important than factor B, and factor B is more important than factor C. At the same time, factor C is more important than factor A. The consistency check removes data that does not meet this requirement. The CR value is calculated as follows:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (4-1)$$

$$CR = \frac{CI}{RI} \quad (4-2)$$

Where λ_{\max} is the maximum eigenvalue of the corresponding matrix, n is the number of criteria for the corresponding matrix, CI is the consistency index, and RI is the random index defined by Saaty (Saaty 2004).

Step 5. Determine the weight of each influencing factor. The weight vector W is then normalized by each weight of factors $d(A_i)$.

$$W = (d(A1), d(A2), \dots, d(An))^T \quad (4-3)$$

For each factor, the final weight W_i is the arithmetic mean of the results from all experts.

$$W_i = \frac{1}{n} \sum W \quad (4-4)$$

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

Weighted Overlay Analysis

In order to answer which areas or properties are best suitable for deconstruction, we ranked the areas based on the above factors and their weights. The map-based ranking is used for site selection research and feasibility analysis (Wang et al. 2009; Sumathi, Natesan, and Sarkar 2008). After combining with AHP, the higher-ranked area represents the most likely deconstructed area considering all factors and weighted overlay layers (Şener et al. 2010; Ding et al. 2018). The combination of GIS analysis and AHP was reflected in the correspondence between factors and map layers, and the correspondence between their weights. The factors used in the AHP model were converted into map layers through geographic information data, and the weights analyzed by the AHP model were used for weighted overlay. The steps for weighted overlay analysis are as follows.

Step 1. Data Acquisition. The geographic information data representing different factors come from different open-source websites. The public website of the City of Pittsburgh (The City of Pittsburgh 2021), the public geographic information website of Pennsylvania and Pittsburgh can find the geographic information data that meets the factors (WPRDC 2021).

Step2. Factor Conversion. Based on the geographic information data set we found, this paper mapped the influencing factors in the AHP model to the corresponding geographic information system map layers one by one.

Step 3. Buffer Analysis. Buffer analysis is used to analyze factors that are related to distance or can be expressed by distance (Ding et al. 2018). The distance between the deconstruction project site and the groundwater resource and the distance from the landfill represents the level of the specific factor. Distance between the nearest road and the deconstruction project site represents the level of transportation cost (Sumathi, Natesan, and Sarkar 2008; Ding et al. 2018).

Based on the evaluation method of landfill site selection research, five levels are set respectively based on the distance unit of 500 meters (1640 ft, ~0.3 miles): 5 points:

less than 500 meters (1640 ft, -0.3 miles); 4 points: less than 1000 meters (3280 ft, -0.6 miles); 3 points: less than 1500 meters (4921 ft, -0.9 miles); 4 points: Less than 2000 meters (6561 ft, -1.2 miles); 5 points: less than 2500 meters (8202 ft, -1.5 miles) (Sumathi, Natesan, and Sarkar 2008).

Step 4. Raster Analysis. Raster analysis is used to analyze factors with regional characteristics (AlZaghrini, Srour, and Srour 2019). The urban development level, air quality, and the number of condemned buildings in different neighborhoods are analyzed by raster analysis. According to the raster distribution, five levels have been made by equally dividing the raster data.

Step 5. Weighted Overlay Analysis. Weighted overlay analysis uses layers created from buffer and raster analysis. The weight of layers is consistent with 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.

FINDINGS

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

Importance of Influencing Criteria with AHP Analysis

Table 4.3 and **Figure 4.4** below show the relative 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 a relative weight of 46%, which indicates the percentage of environment criteria when deciding about deconstruction is 46%. Meanwhile, it also indicates that it is the most important factor only compared with the other three criteria. The environment criterion is near twice the importance of the resource criterion based on the concept of AHP. Different building types seem not to affect the decision-making of deconstruction in Pittsburgh.

Table 4.3: Relative Importance and Rank of Criteria

	Expert 1 Alicia Carberry	Expert 2 Terry Wiles	Expert 3 Sarah Kinter	Relative 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*	0.09	0.06	0.03	-	-

* The consistency rate for all criteria is below 0.1, indicating there is no contradiction between the pairwise comparisons of each expert, or the contradiction can be accepted.

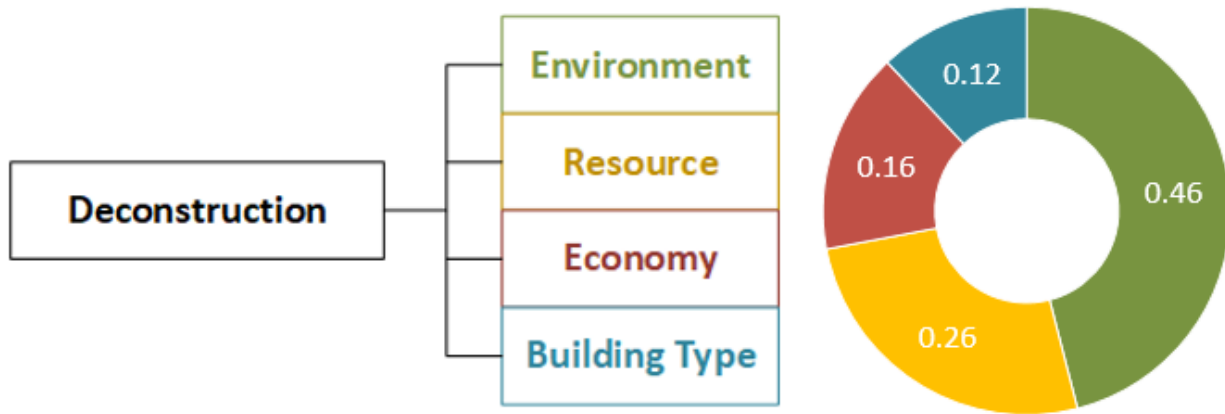


Figure 4.4: Relative Weights of Four Criteria

Detailed information is also displayed in **Table 4.3**. The first column contains all factors in the same layer with the result of CR from the consistency check process. The second to the fourth columns show the weights and relative importance from different experts' perspectives. The detailed information of experts is summarized in the Analytic Hierarchy Process section. The fifth column shows the final weights for each factor based on the result from all experts. The rank is based on the final weights, which shows the importance of these factors after all experts' opinions are combined.

Importance of Influencing Environmental Factors with AHP Analysis

Table 4.4 and **Figure 4.5** provide the relative importance and rank of three environmental factors. Among all environmental factors, the most significant impact on deconstruction is the health impact of the project environment, which includes 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, from either perspective of environmental friendliness or human living health, responses from experts indicate this to be the most important factor in comparison to others. This further demonstrates why the biosafety disposal of hazardous materials is one of the key tasks of deconstruction.

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 may not have a substantial impact on the decision-making of the deconstruction project.

Table 4.4: Relative Importance and Rank of Environmental Factors

	Expert 1 Alicia Carberry	Expert 2 Terry Wiles	Expert 3 Sarah Kinter	Relative Weight	Rank
Health Criteria	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*	0.07	0.07	0.00	-	-

* The consistency rate for all criteria is below 0.1, indicating there is no contradiction between the pairwise comparisons of each expert, or the contradiction can be accepted.

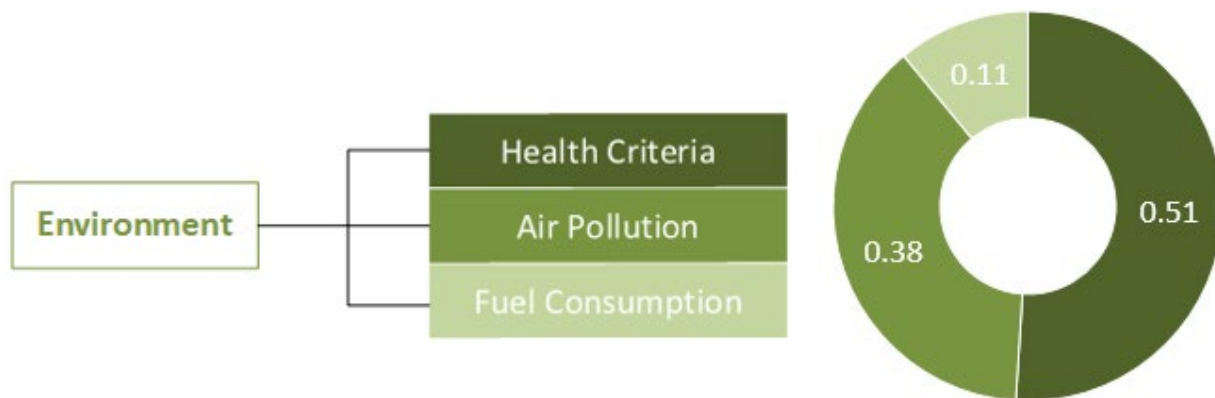


Figure 4.5: Relative Weights of Environmental Factors

Importance of Influencing Resources Factors with AHP Analysis

Table 4.5 and **Figure 4.6** provide the relative importance and rank of four resources factors. Landfill resources are not one of the key resources that deconstruction activities focus on. In fact, one of the purposes of deconstruction activities is to reduce the waste of resources entering a landfill, so experts do not pay much attention to the landfill site. Important factors are the potential impact of groundwater resources and the total amount of renewable and recycled materials brought by the project.

Energy resource is an easily overlooked factor. Although these experts are not paying much attention to this factor, an interesting conclusion from them is that compared with demolition, deconstruction projects will require more professional equipment, which makes energy resources affect the choice of deconstruction projects to a certain extent. Excessive energy consumed by machinery will have a negative impact.

Table 4.5: Relative Importance and Rank of Resources Factors

	Expert 1 Alicia Carberry	Expert 2 Terry Wiles	Expert 3 Sarah Kinter	Relative 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*	0.03	0.04	0.09	-	-

* The consistency rate for all criteria is below 0.1, indicating there is no contradiction between the pairwise comparisons of each expert, or the contradiction can be accepted.



Figure 4.6: Relative Weights of Resources Factors

Importance of Influencing Economic Factors with AHP Analysis

Table 4.6 and Figure 4.7 provide 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 not be affected by the development of different neighborhoods.

Table 4.6: Relative Importance and Rank of Economic Factors

	Expert 1 Alicia Carberry	Expert 2 Terry Wiles	Expert 3 Sarah Kinter	Relative 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	-	-

* The consistency rate for all criteria is below 0.1, indicating there is no contradiction between the pairwise comparisons of each expert, or the contradiction can be accepted.

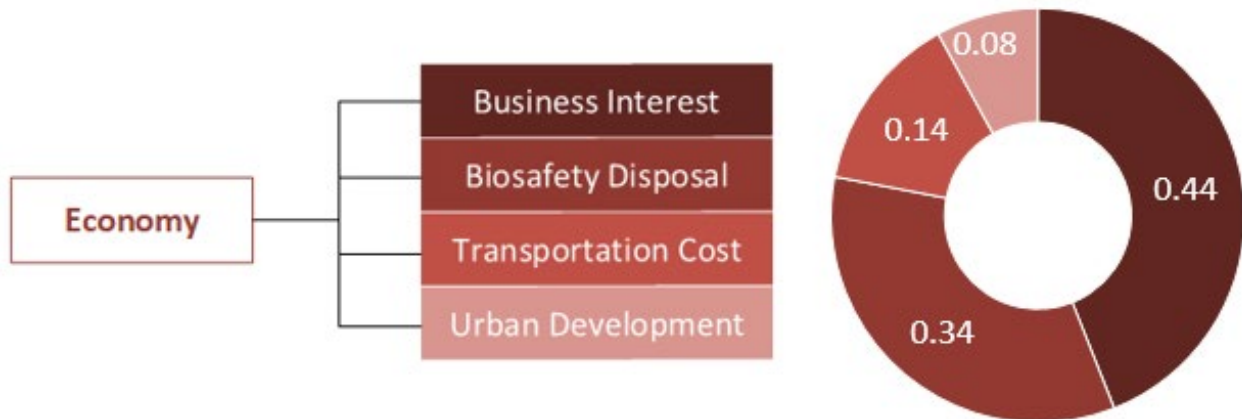


Figure 4.7: Relative Weights of Economic Factors

Importance of Influencing Building Type Factors with AHP Analysis

Table 4.7 and Figure 4.8 provide 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. Therefore, the effective recycling of these components will reduce the cost of other projects. This factor will be one of the important conditions affecting deconstruction in the future. Considering the situation in Pittsburgh, there are not many deconstructions of attractions and landmarks, and we tend to retain the original appearance of these buildings.

Table 4.7: Relative Importance and Rank of Building Type Factors

	Expert 1 Alicia Carberry	Expert 2 Terry Wiles	Expert 3 Sarah Kinter	Relative Weight	Rank
Residential	0.28	0.63	0.63	0.52	1
Commercial	0.58	0.10	0.25	0.32	2
Attractions	0.13	0.25	0.10	0.16	3
CR*	0.07	0.02	0.02	-	-

* The consistency rate for all criteria is below 0.1, indicating there is no contradiction between the pairwise comparisons of each expert, or the contradiction can be accepted.



Figure 4.8: Relative Weights of Building Types

These findings provide the relative importance of different factors in the same criterion or layer. The weights of factors are then used for weighted overlay layers to find the neighborhoods which meet the majority of factors requirements under a high level. The section below shows the detailed findings for the overlay analysis.

Potential Deconstruction Areas Considering Environmental Factors

Figure 4.9 to **Figure 4.11** shows the basic maps of air pollution, health criteria, and fuel consumption. The air pollution map used overall air quality data from all air quality monitors in Pittsburgh and averaged calculations for each census tract. The health criteria map used pollutant and asbestos information of each census tract for measurement. The basis of the fuel consumption map is the building carbon footprint of the Pittsburgh area. According to the frequency of construction activities in the past, the carbon footprint data are averaged for each census tract, which is consistent with Assefa's research with different construction scenarios (Assefa and Ambler 2017). The level classification adopts the method of raster analysis.

Figure 4.12 shows the result for potential deconstruction areas only considering the combined environmental factors of air pollution, health criteria, and fuel consumption. 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. In the GIS map, the areas with a color closest to red represents that these areas can better meet the requirements of these factors when all three environmental factors are weighted according to the AHP. In this paragraph, air pollution and health criteria dominate the choice of regions because of the high percentage of weight.

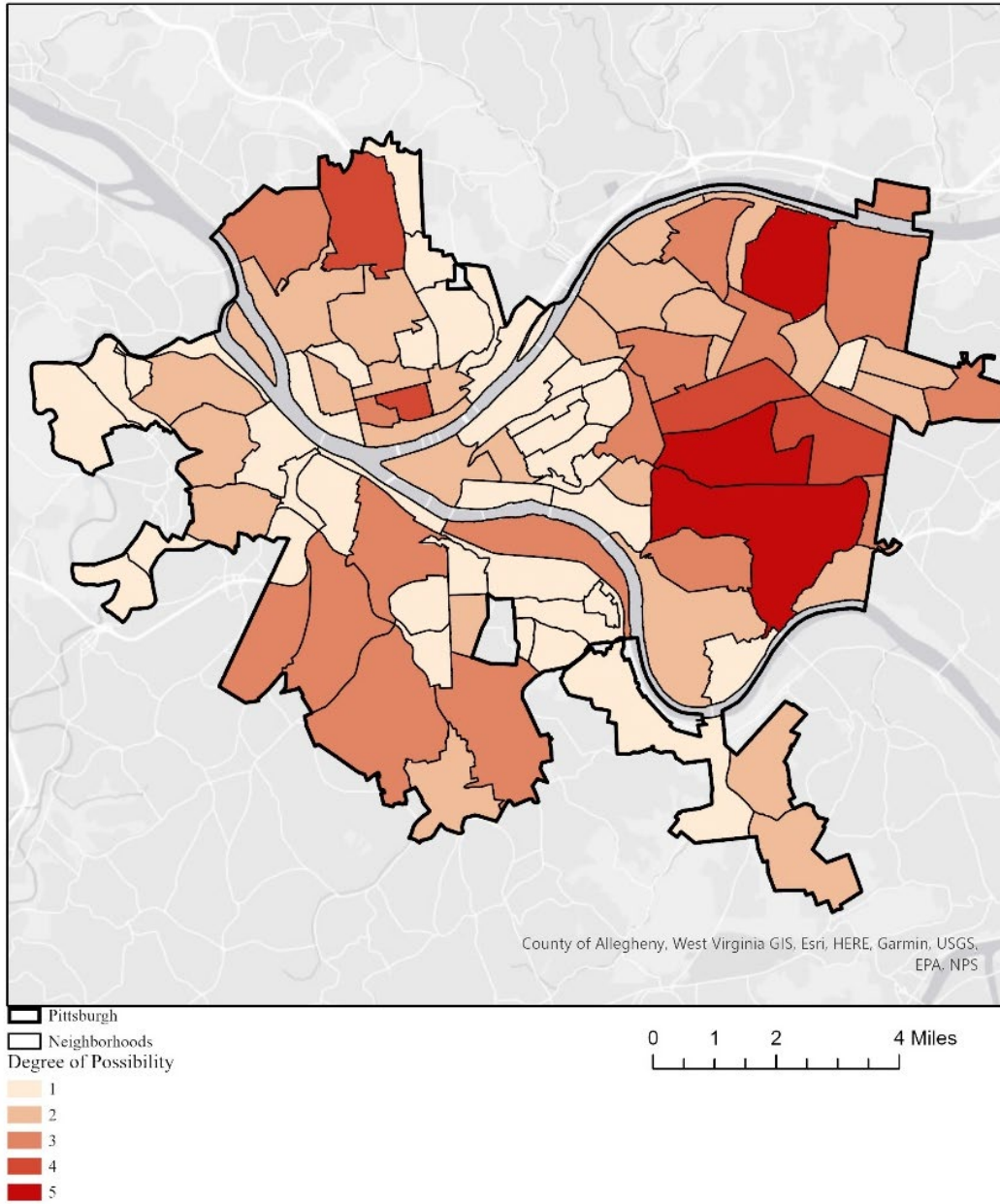


Figure 4.9: Air Pollution Layer

Data Source: <https://data.wprdc.org/dataset/allegheny-county-air-quality> (air quality)

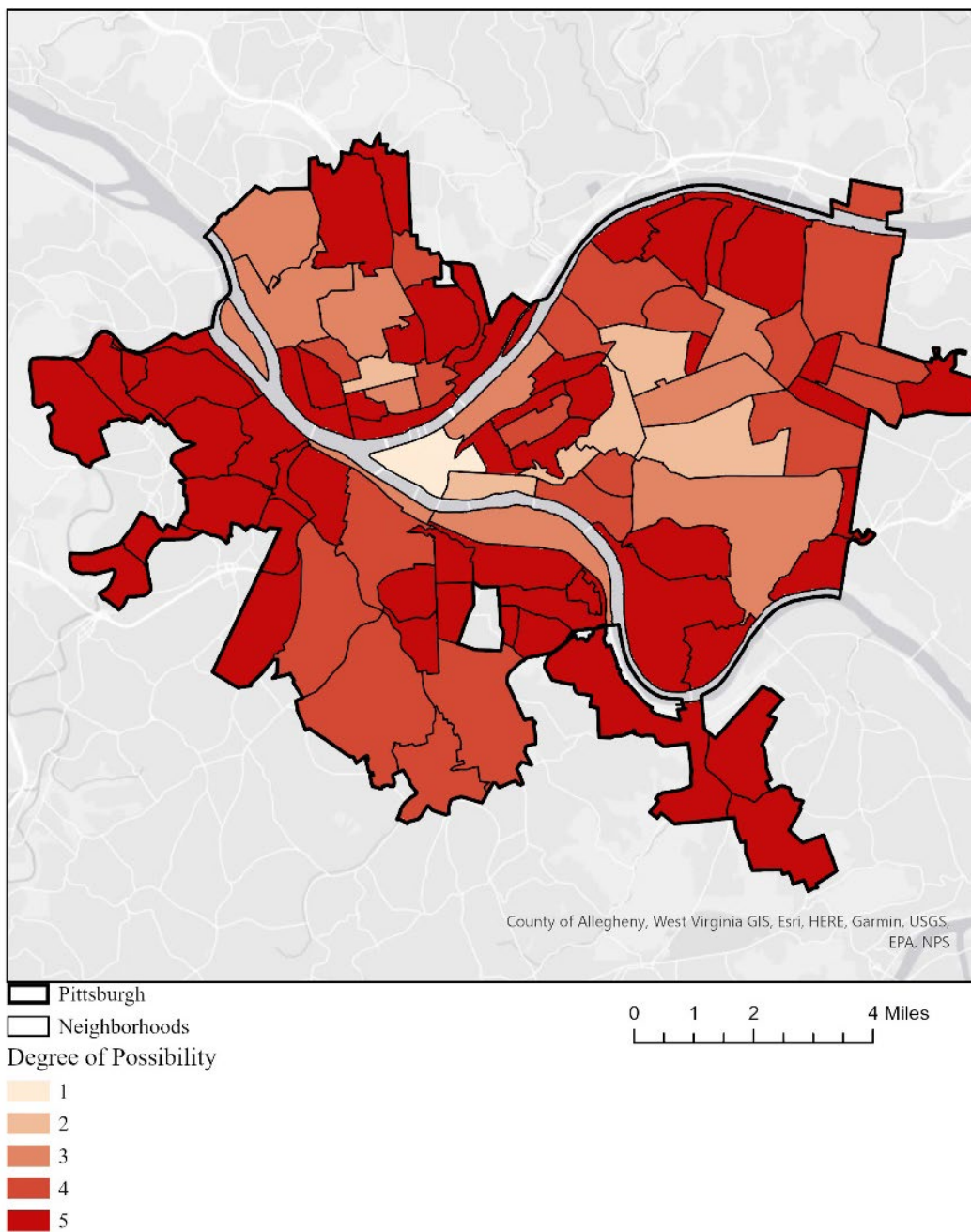


Figure 4.10: Health Criteria Layer

Data Source: <https://data.wprdc.org/dataset/allegheny-county-asbestos-permit>
 (health criteria)

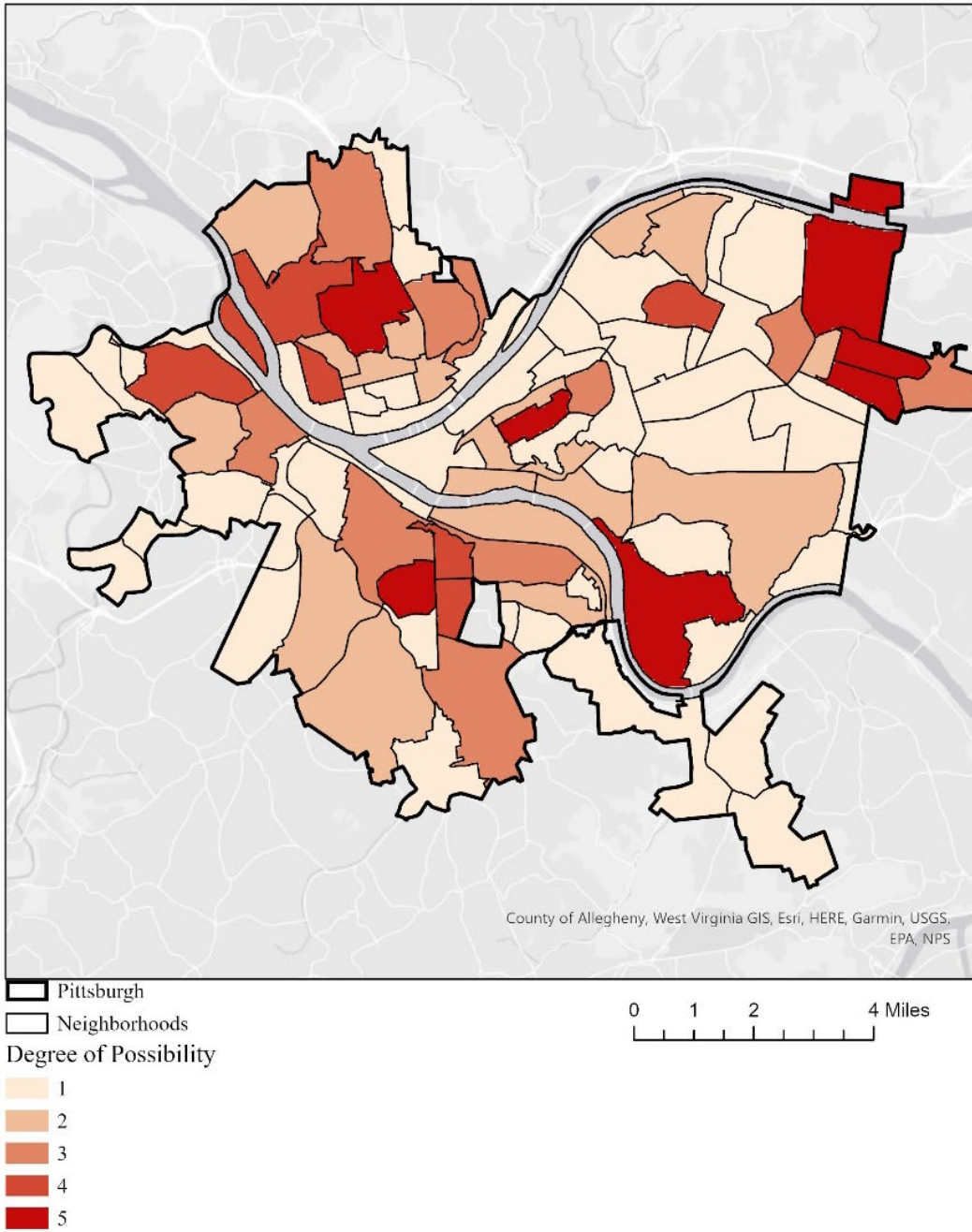


Figure 4.11: Fuel Consumption Layer

Data Source: <https://data.wprdc.org/dataset/alleggheny-county-building-footprint-locations1> (fuel consumption)

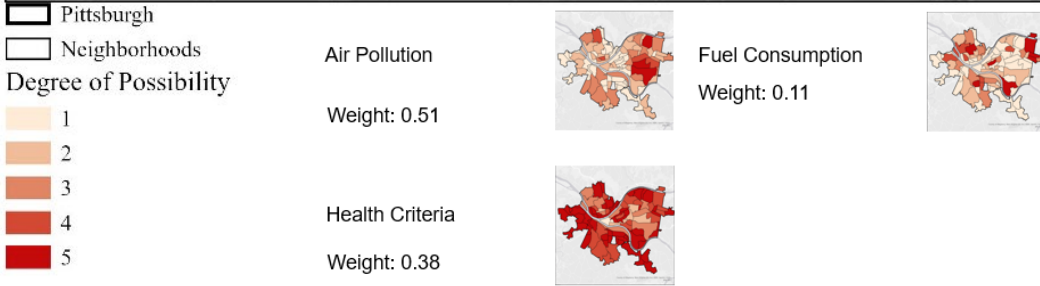
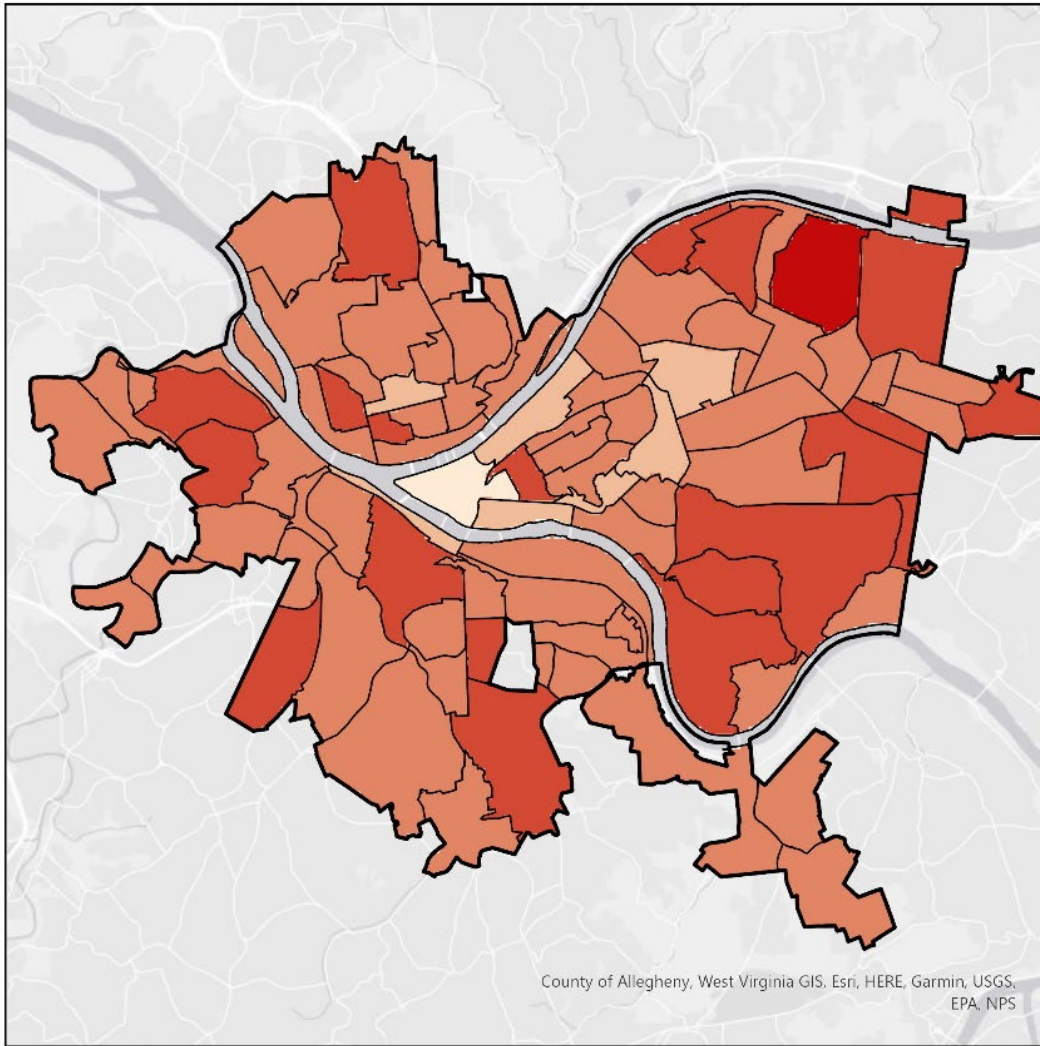


Figure 4.12: Environmental Factors Combined

Potential Deconstruction Areas Considering Resources Factors

Figure 4.13 to **Figure 4.16** show the basic maps of the landfill, groundwater, energy, and recycling materials. The landfill map shows the distance between the potential deconstruction project site to the landfill area based on all the landfill areas in Allegheny County. The groundwater map shows the distance between the potential deconstruction project site and Allegheny County water supply stations. The energy map shows the location of several biggest oil and natural gas energy supply stations in Allegheny County and the distance between them and project sites. The amounts of recycling materials map are based on the condemned buildings in the Pittsburgh area. Due to the lack of specific information on building recyclable materials, in this paper, we used the building carbon footprint to obtain the area of the buildings and used this to determine the potential recyclable materials. All data are averaged and assigned to different levels.

Figure 4.17 show the process and result for potential deconstruction areas only considering four resources factors. We use buffer analysis to obtain the range of areas that meet the requirements of the factors and divide them into five levels. The area located in the center of the buffer is closer to the location of resource facilities. We overlap all buffers and find that some 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.

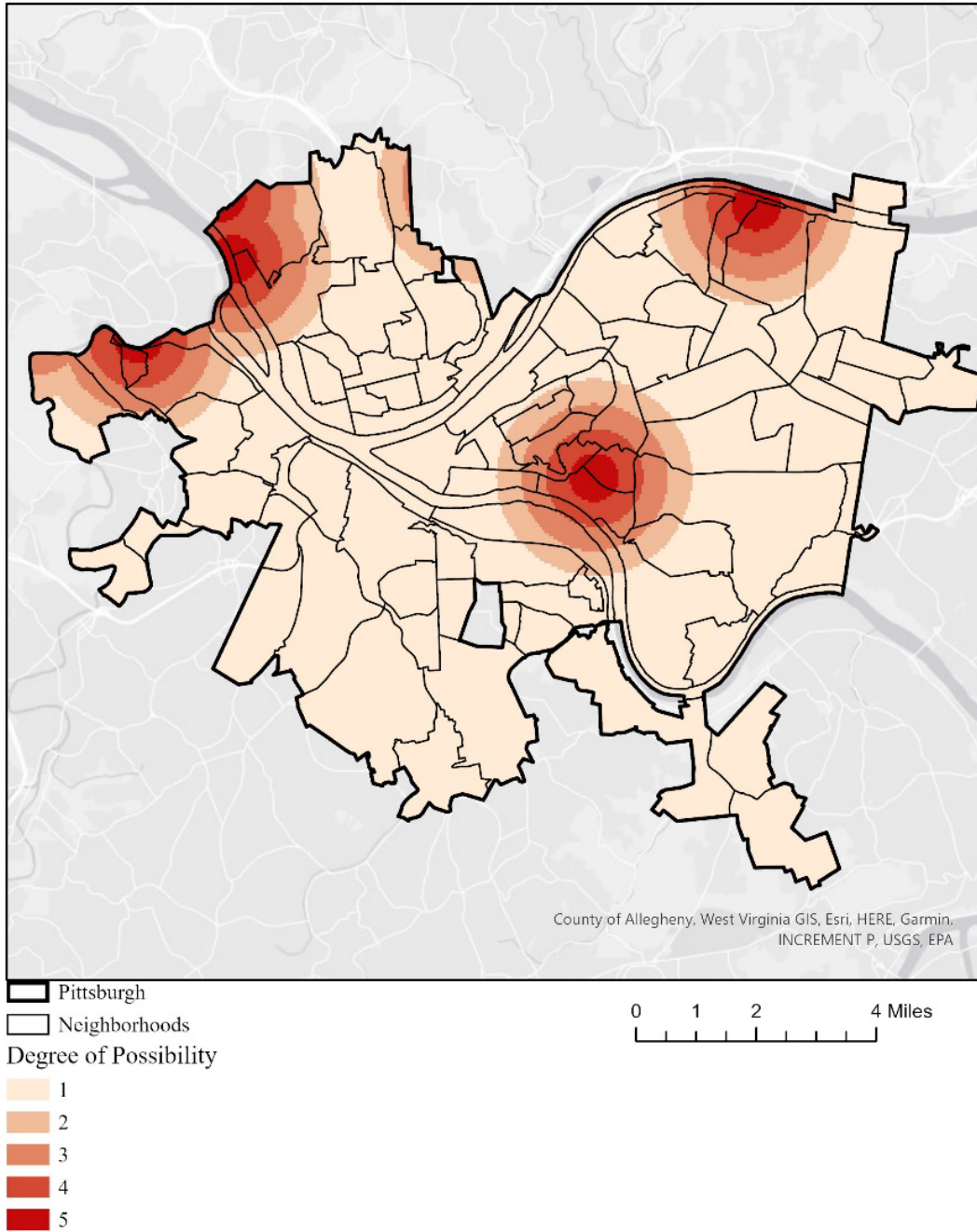


Figure 4.13: Landfill Layer

Data Source:

<https://www.dep.pa.gov/Business/Land/Waste/SolidWaste/MunicipalWaste/MunicipalWastePermitting/Pages/MW-Landfills-and-Resource-Recovery-Facilities.aspx> (landfill)

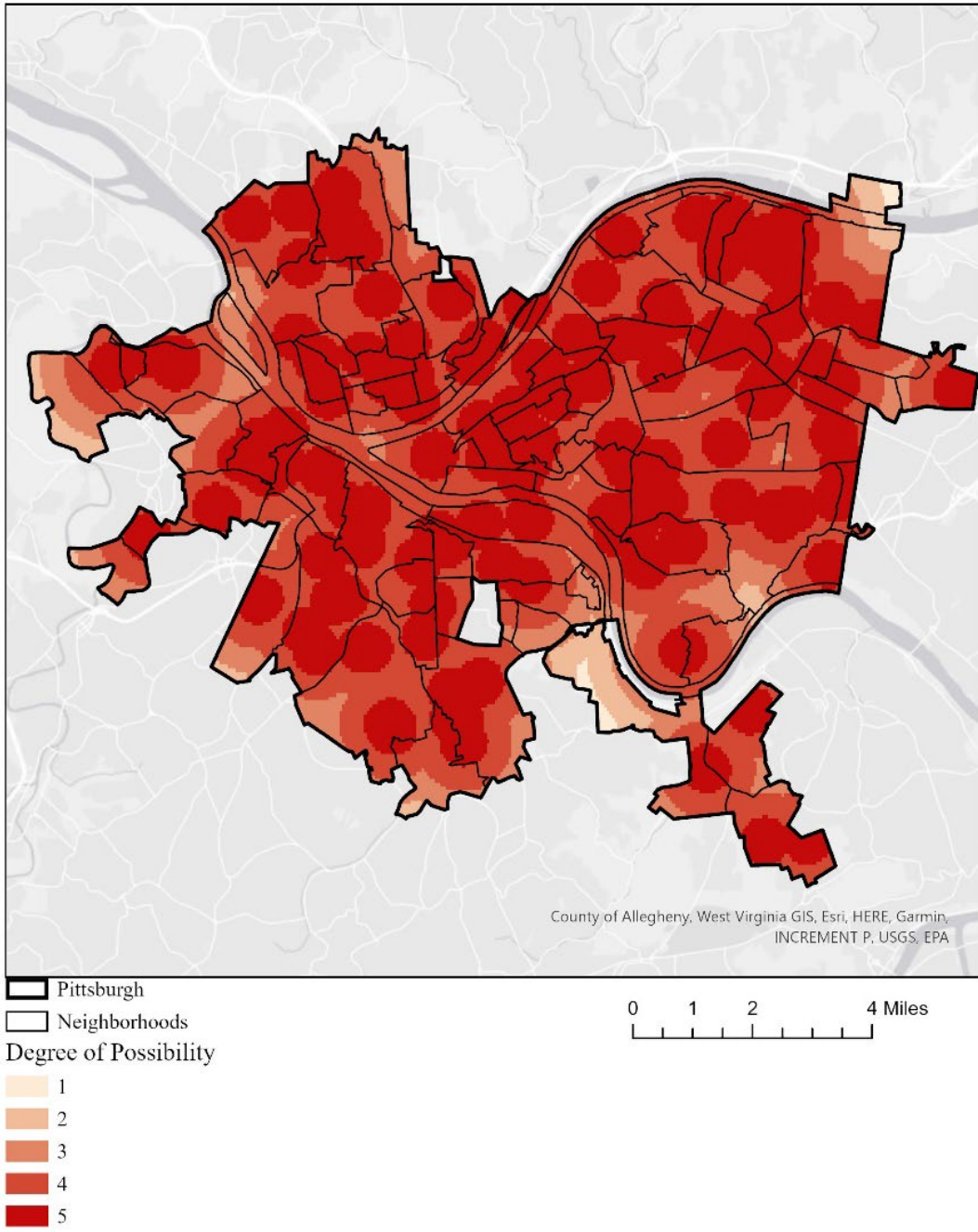


Figure 4.14: Groundwater Layer

Data Source: [https://data.wprdc.org/dataset/city-water-features \(groundwater\)](https://data.wprdc.org/dataset/city-water-features%20(groundwater))

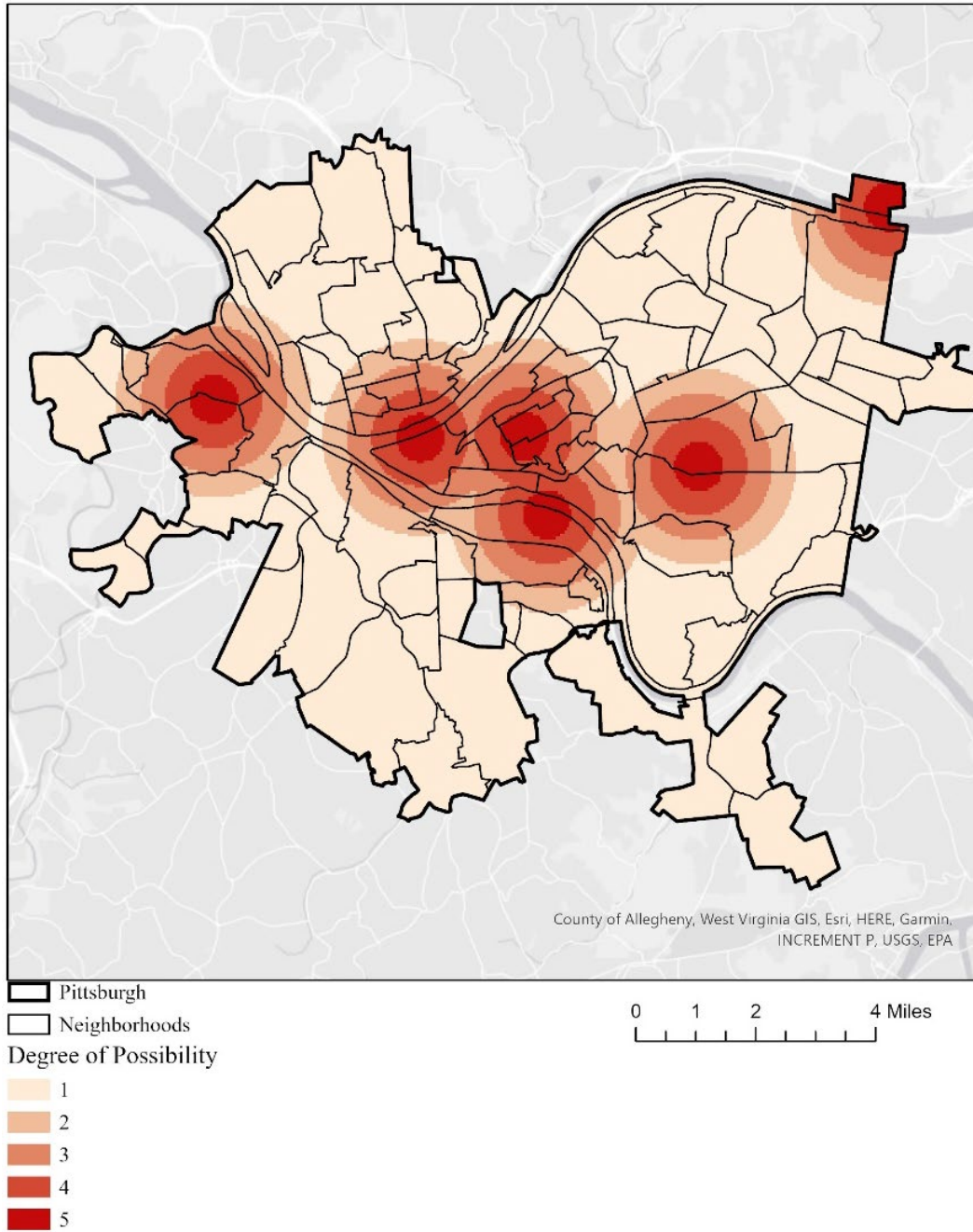


Figure 4.15: Energy Layer

Data Source: <https://data.wprdc.org/dataset/alleghey-county-energy-and-water-use>
(energy)

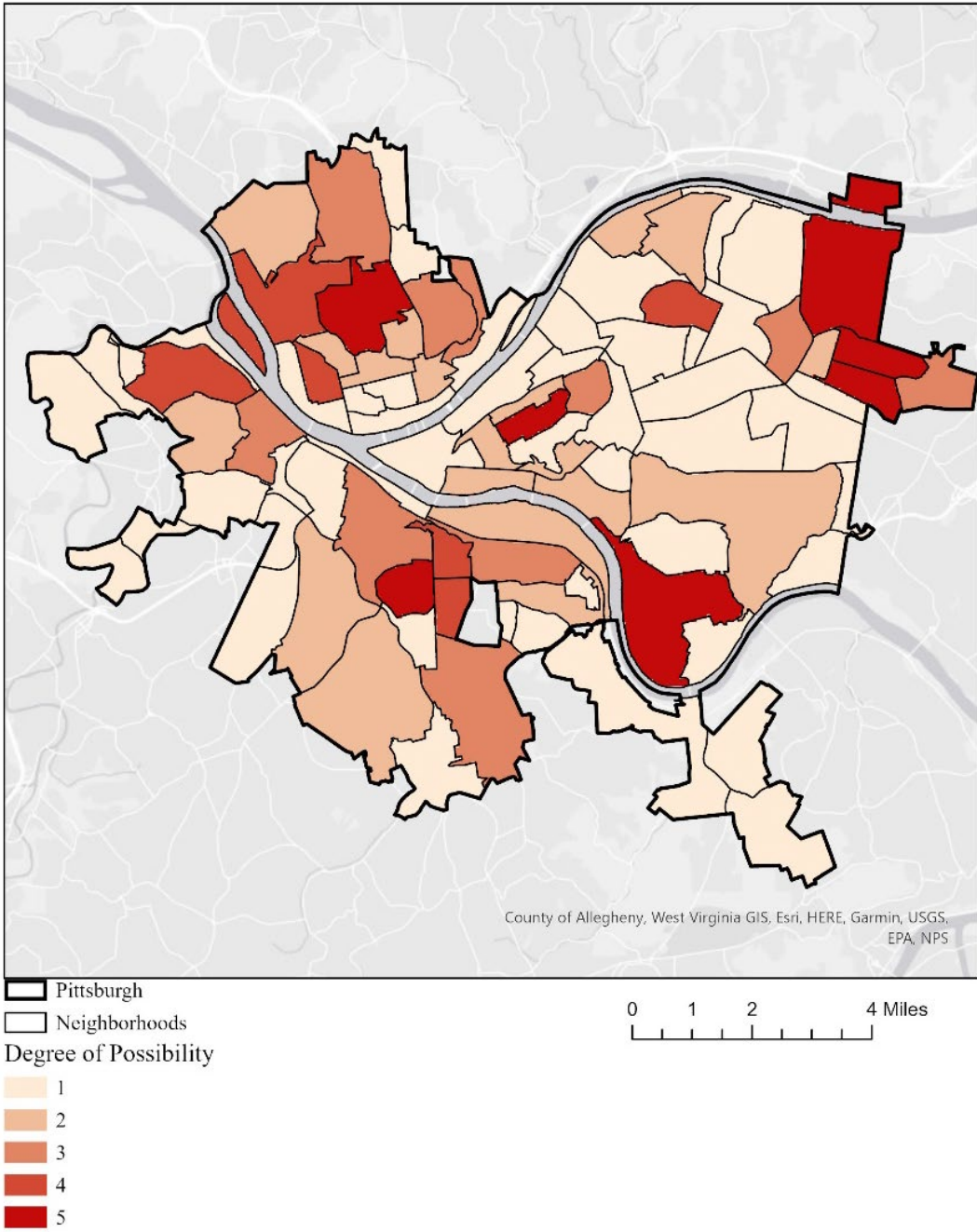


Figure 4.16: Layer of Recycling Materials

Data Source: [https://pittsburghpa.gov/pli/condemned-under-contract-razed-properties\(materials\)](https://pittsburghpa.gov/pli/condemned-under-contract-razed-properties(materials))

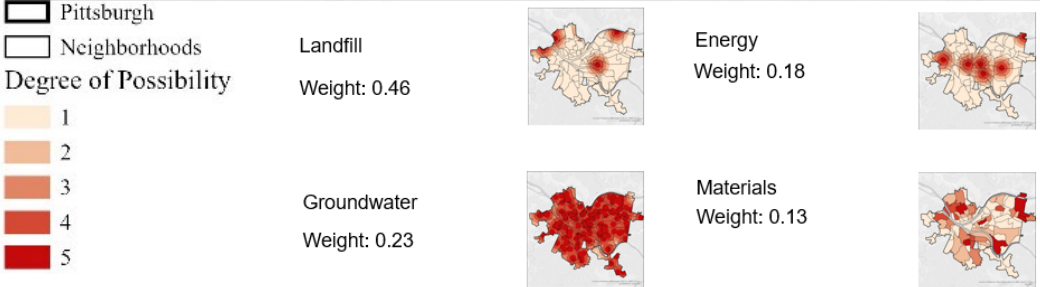
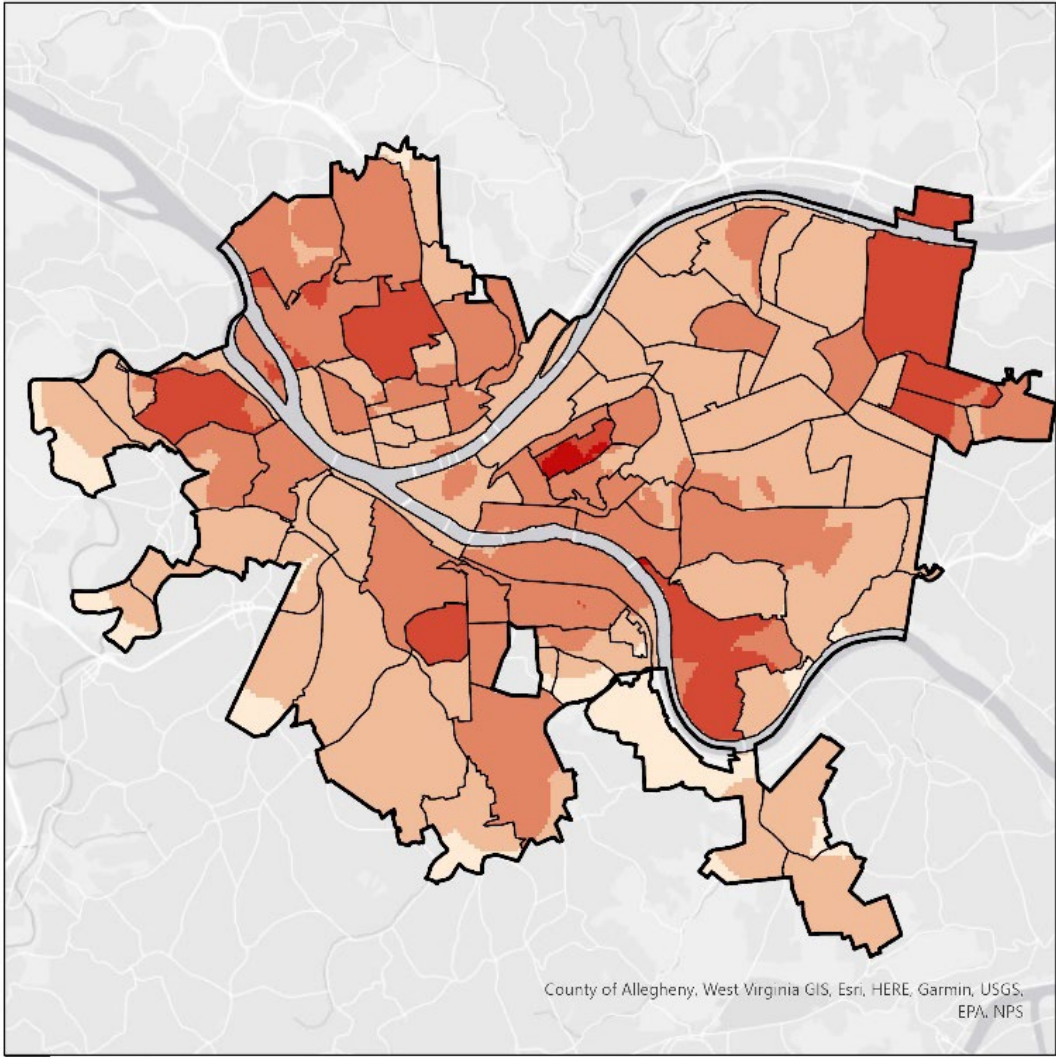


Figure 4.17: Resource Factors Combined

Potential Deconstruction Areas Considering Economic Factors

Figure 4.18 to **Figure 4.21** show the basic maps of urban development, transportation cost, biosafety disposal cost, and business interest. The map of urban development is developed based on the data of market value created by construction activities and existing buildings in Alleghany County. 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. The business interest is developed by the number of condemned buildings in census tract level with the market information of the same area.

Figure 4.22 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 meet simultaneously to obtain good benefits and spend less.

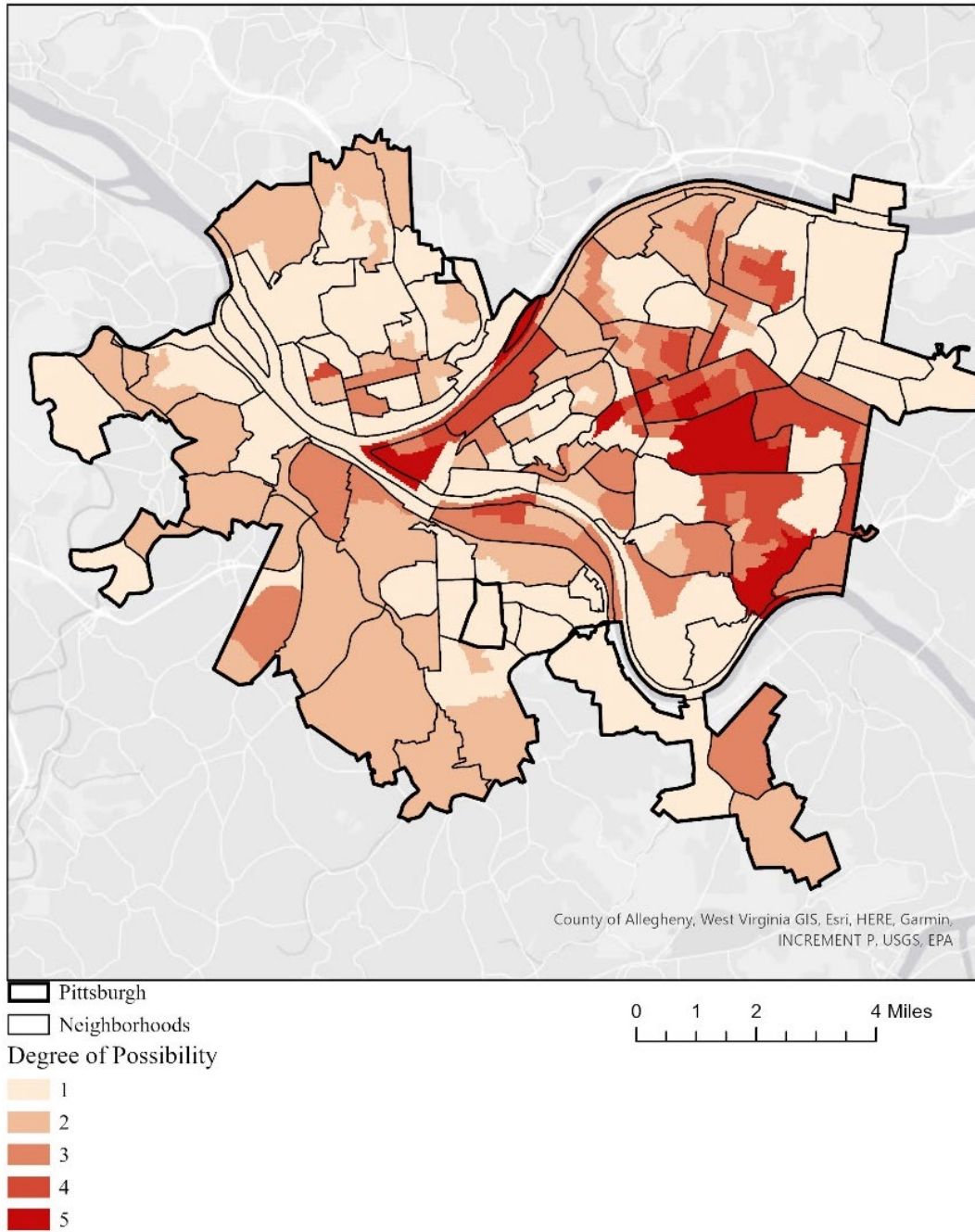


Figure 4.18: Urban Development Layer

Data Source: <https://data.wprdc.org/dataset/market-value-analysis-allegheny-county-economic-development-urban-development>

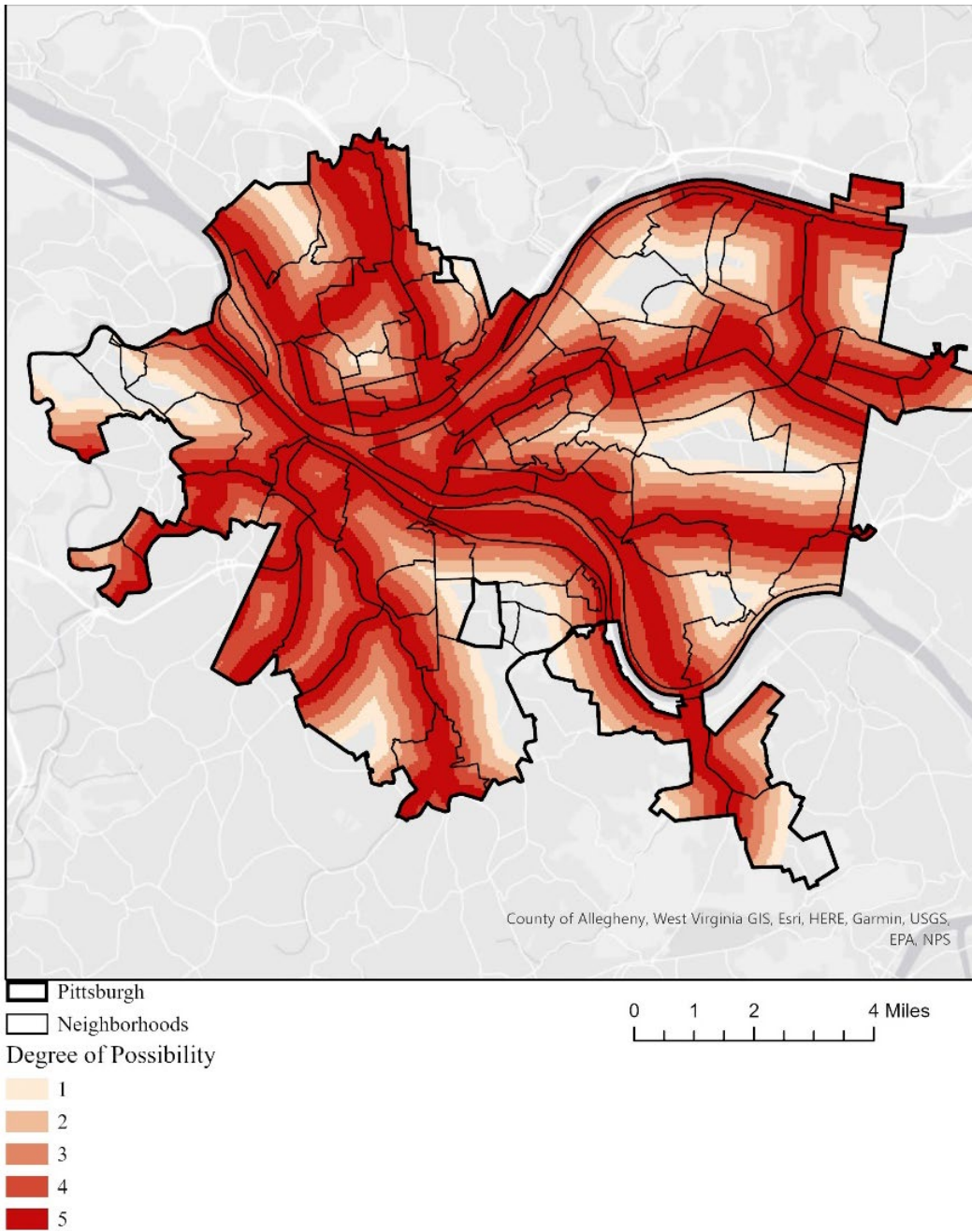


Figure 4.19: Transportation Cost Layer

Data Source: <https://www.census.gov/cgi-bin/geo/shapefiles/index.php?year=2021&layergroup=Roads> (transportation cost)

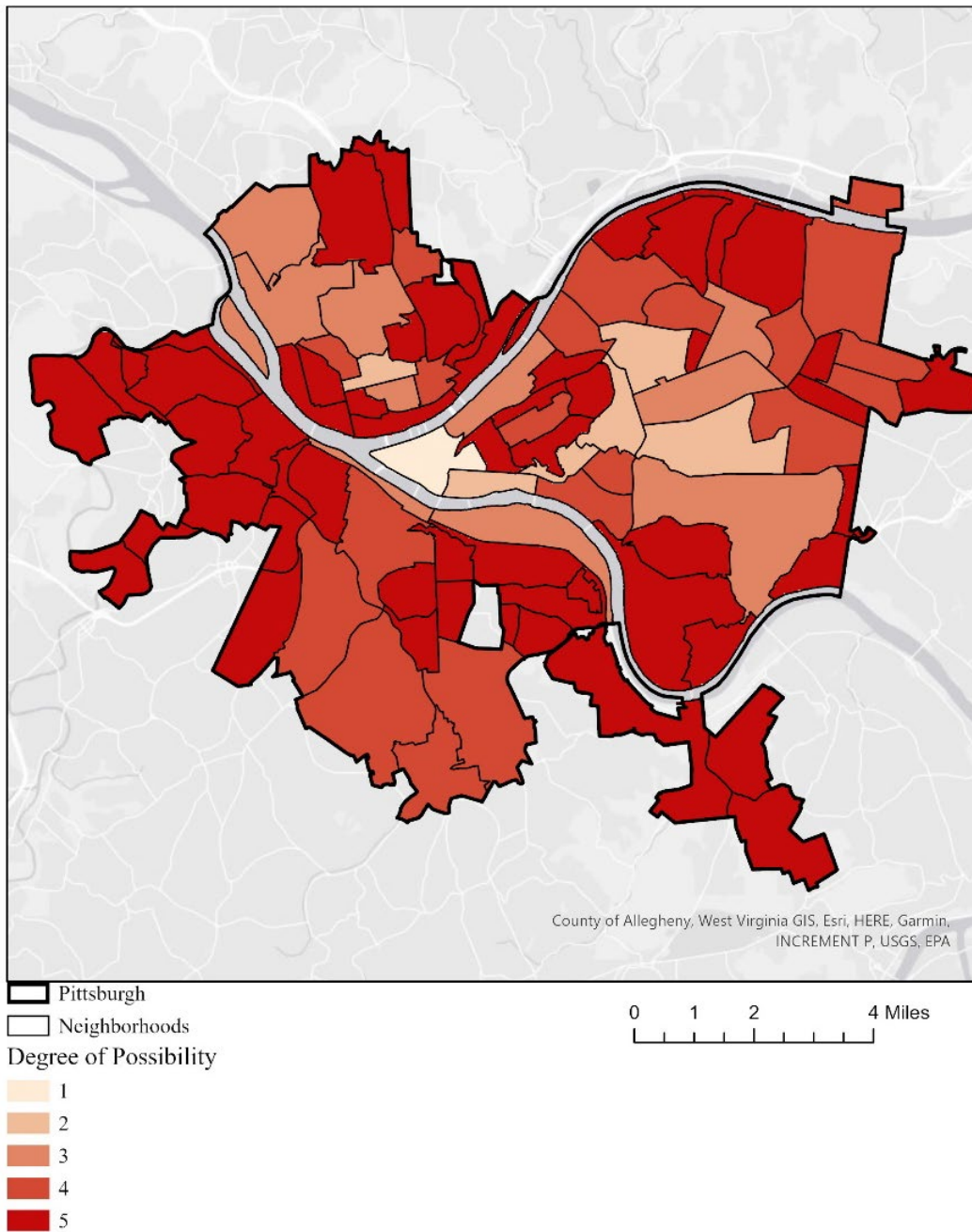


Figure 4.20: Biosafety Disposal Cost Layer

Data Source: <https://data.wprdc.org/dataset/allegheeny-county-asbestos-permit>
 (biosafety disposal cost)

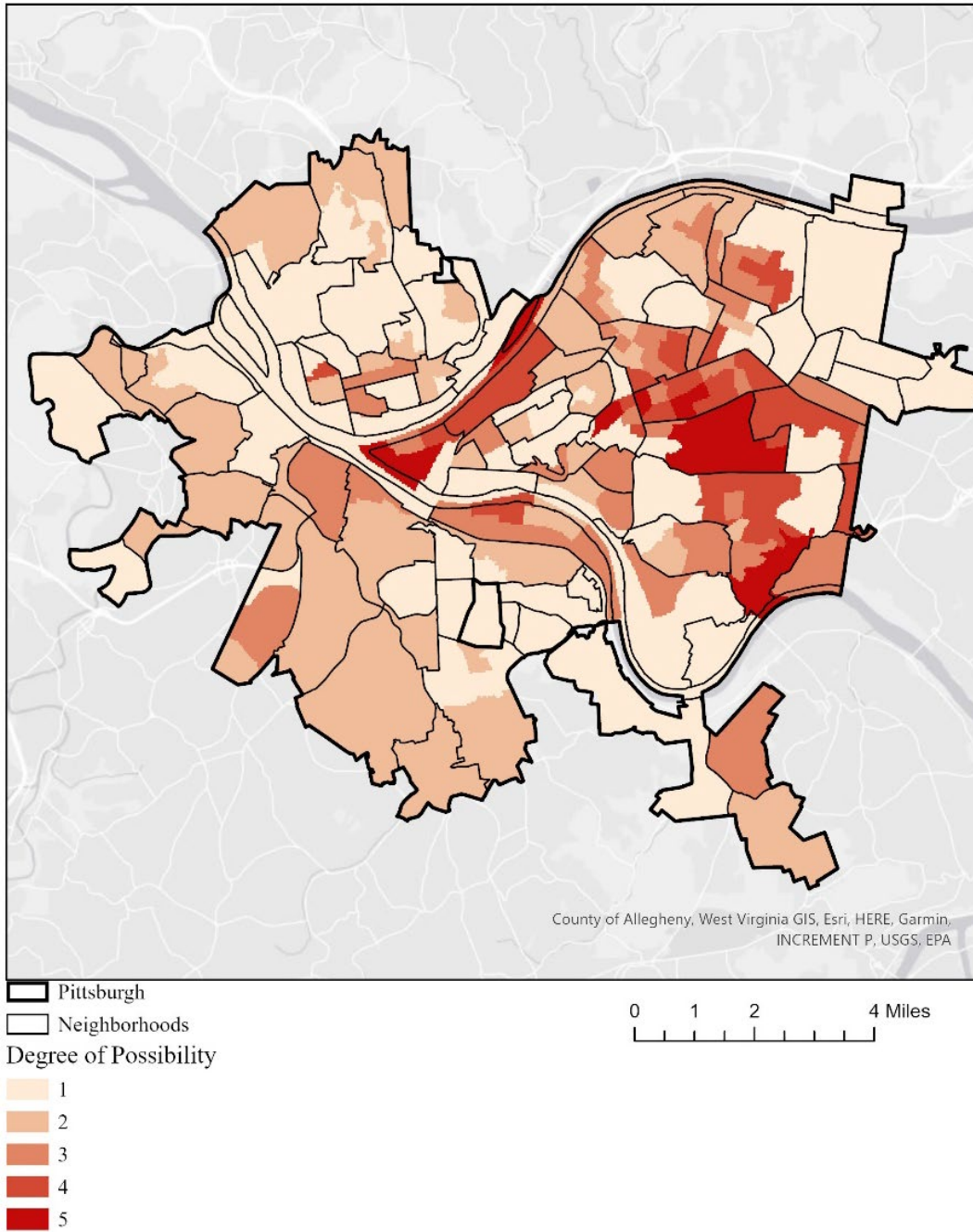


Figure 4.21: Business Interest Layer

Data Source: <https://data.wprdc.org/dataset/market-value-analysis-allegheny-county-economic-development-business-interest>

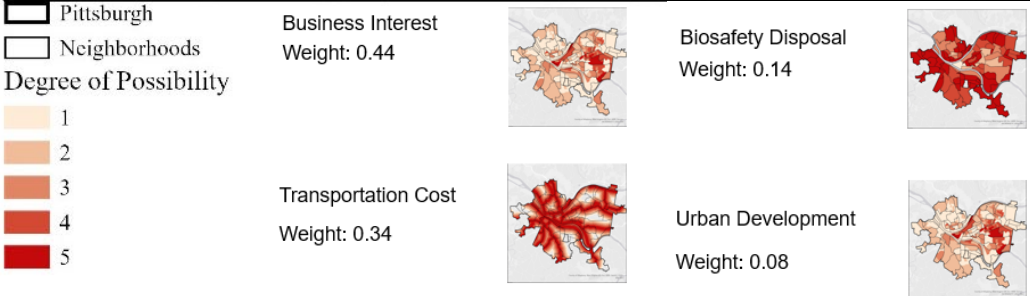
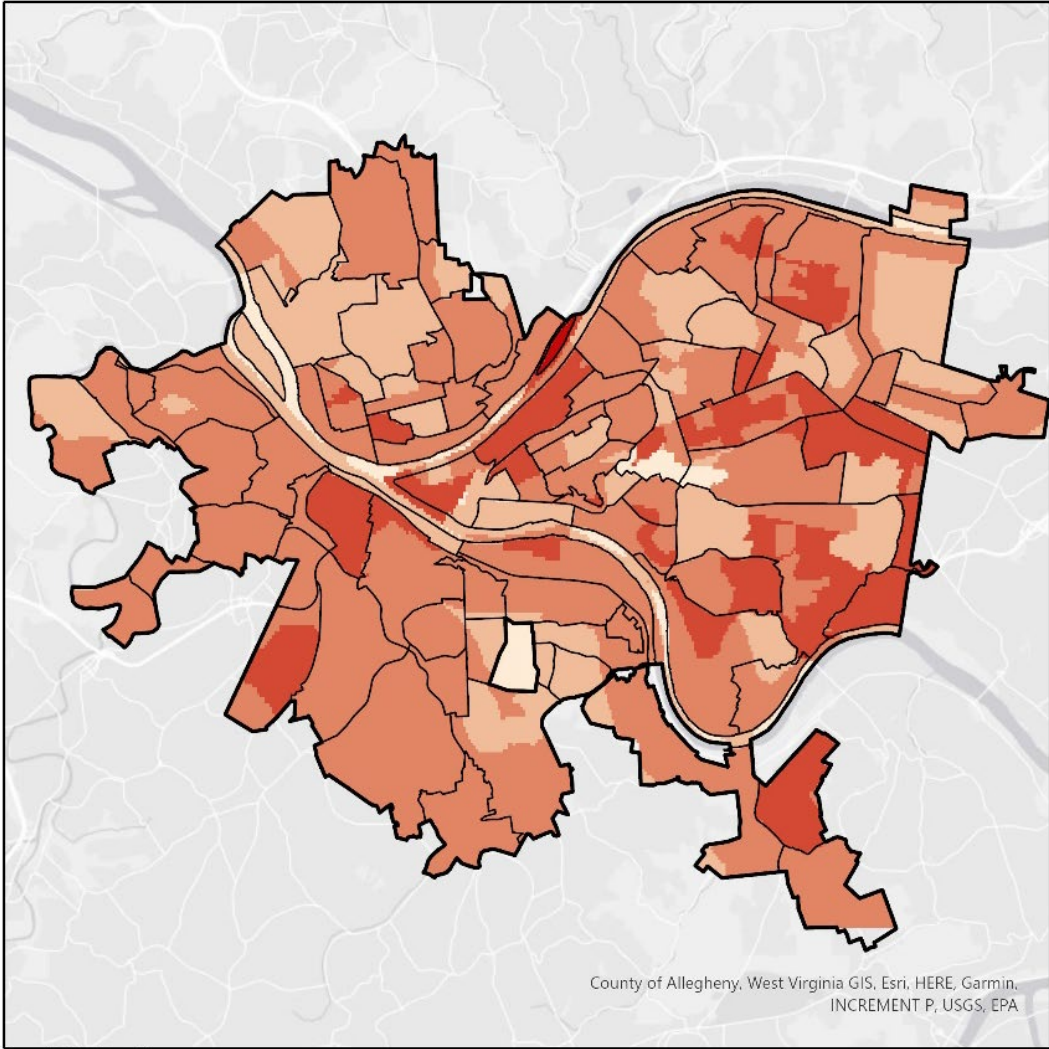


Figure 4.22: Economic Factors Combined

*Potential Deconstruction Areas Considering **Building Type Factors***

Figure 4.23 to **Figure 4.25** shows the basic maps of the condemned residential building, condemned commercial buildings, and condemned attractions. These maps are developed based on the distribution of condemned buildings in the Pittsburgh area. The data of condemned buildings are averaged by census tract.

Figure 4.26 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.

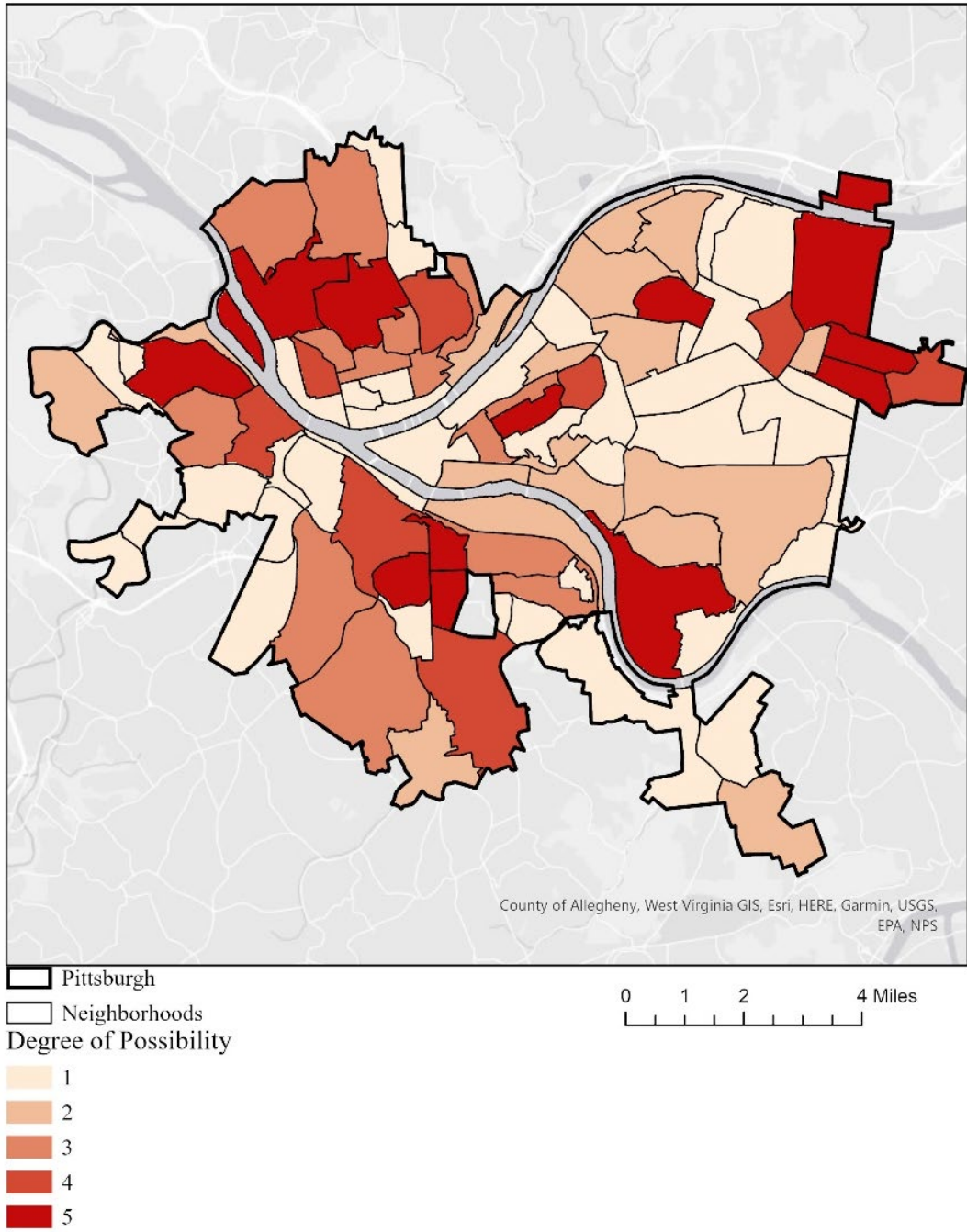


Figure 4.23: Condemned Residential Buildings Layer

Data Source: <https://pittsburghpa.gov/pli/condemned-under-contract-razed-properties>

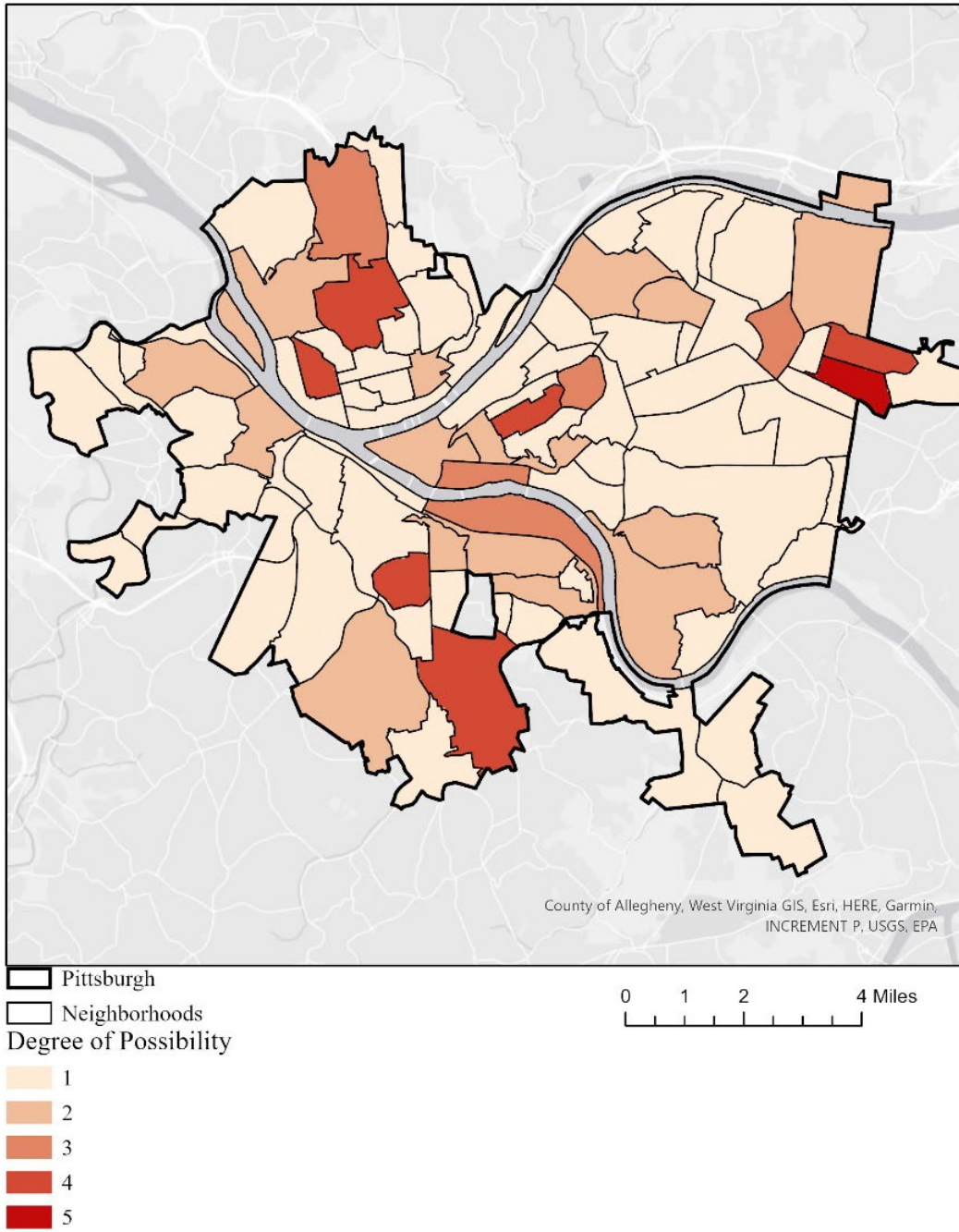


Figure 4.24: Condemned Commercial Buildings Layer

Data Source: <https://pittsburghpa.gov/pli/condemned-under-contract-razed-properties>

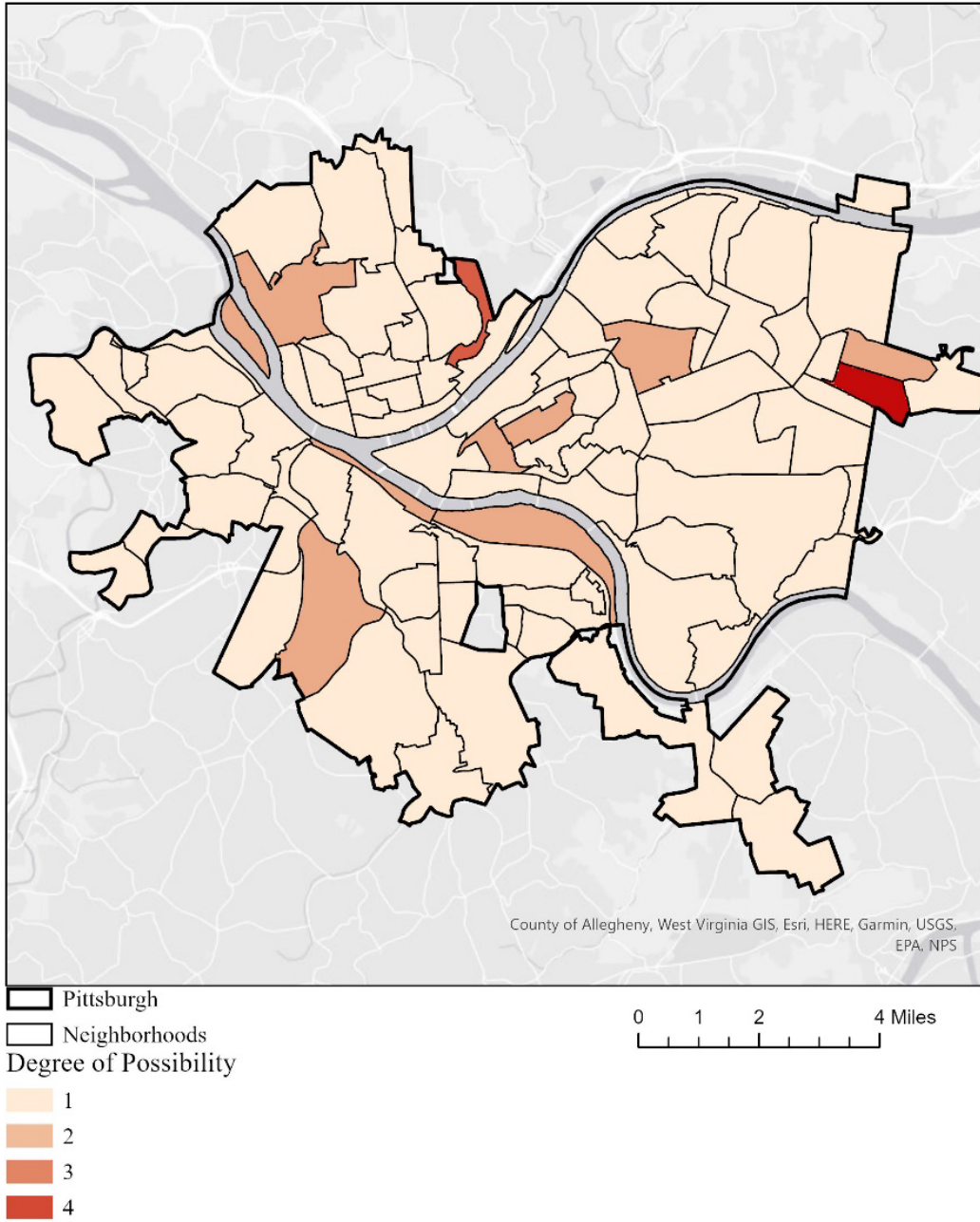


Figure 4.25: Condemned Attractions Layer

Data Source: <https://pittsburghpa.gov/pli/condemned-under-contract-razed-properties>

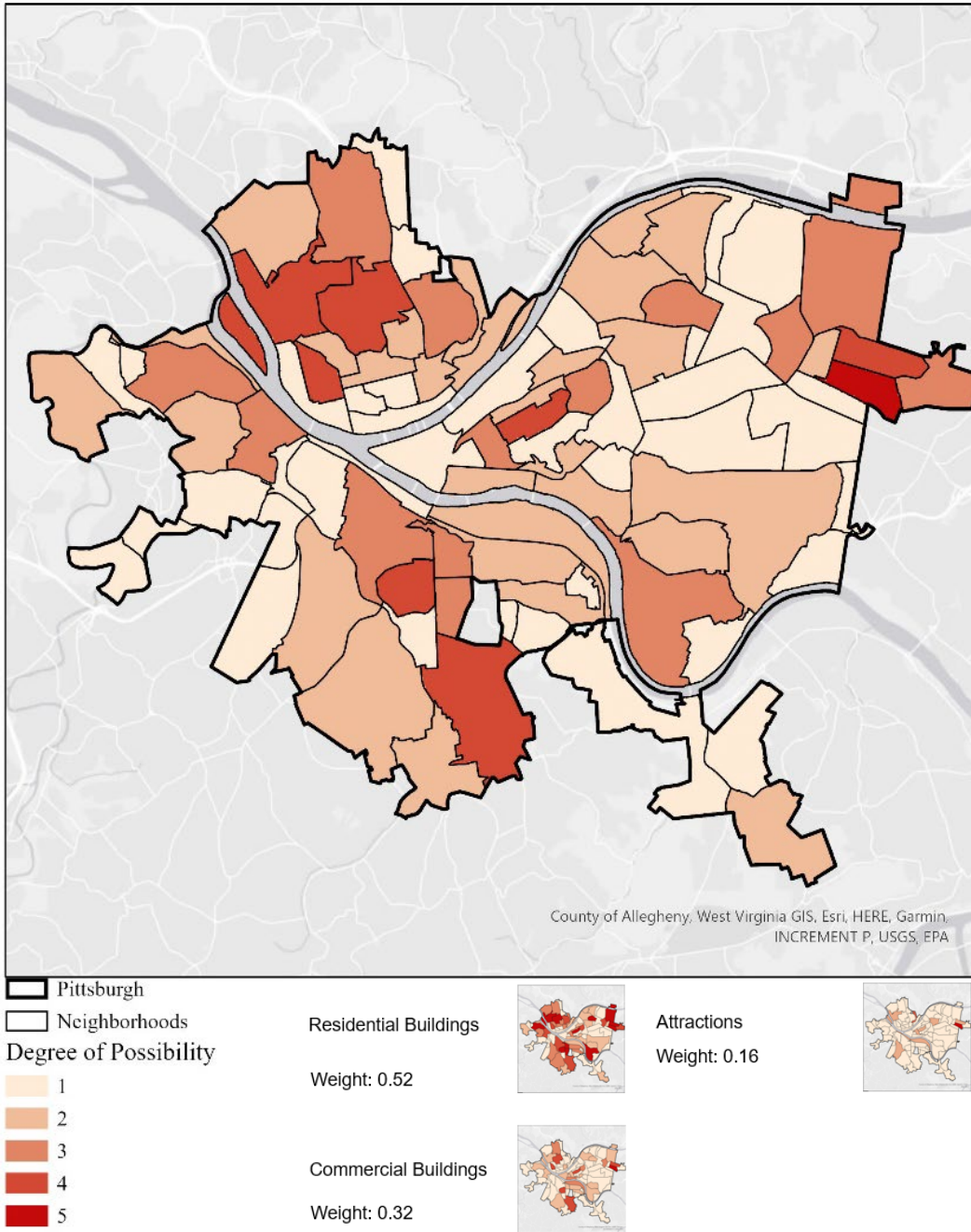


Figure 4.26: Building Type Criteria Combined

Potential Deconstruction Areas Considering Four Main Factors

Figure 4.27 shows the potential deconstruction areas in Pittsburgh considering all factors from the four main categories. Condemned buildings in most areas have a good possibility of being deconstructed. In terms of spatial distribution, these areas are far away from the city center. Neighborhoods such as Homewood South, Lincoln-Lemington-Belmar, Highland Park, Stanton Heights, Squirrel Hill South, Hazelwood, Carrick, Sheraden, Mount Washington, Manchester, Crawford-Roberts, and Dwellings Middle Hill have the highest possibility for deconstruction.

Figure 4.28 then combines the weighted overlay map with the distribution of all condemned buildings and only focuses on the differences between the most possible deconstructed areas with the highest level and the distribution of condemned buildings. The map shows that there is a higher similarity between these datasets. However, there are also some inconsistent areas such as Homewood South, East Hills, Upper Hill, Beltzhoover, and Perry South.

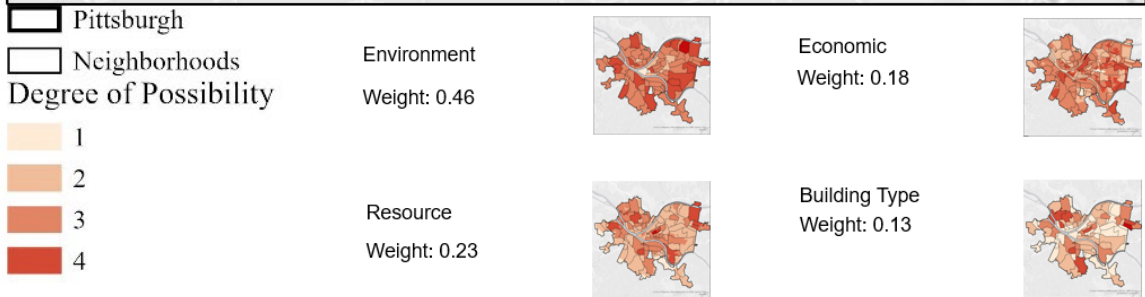
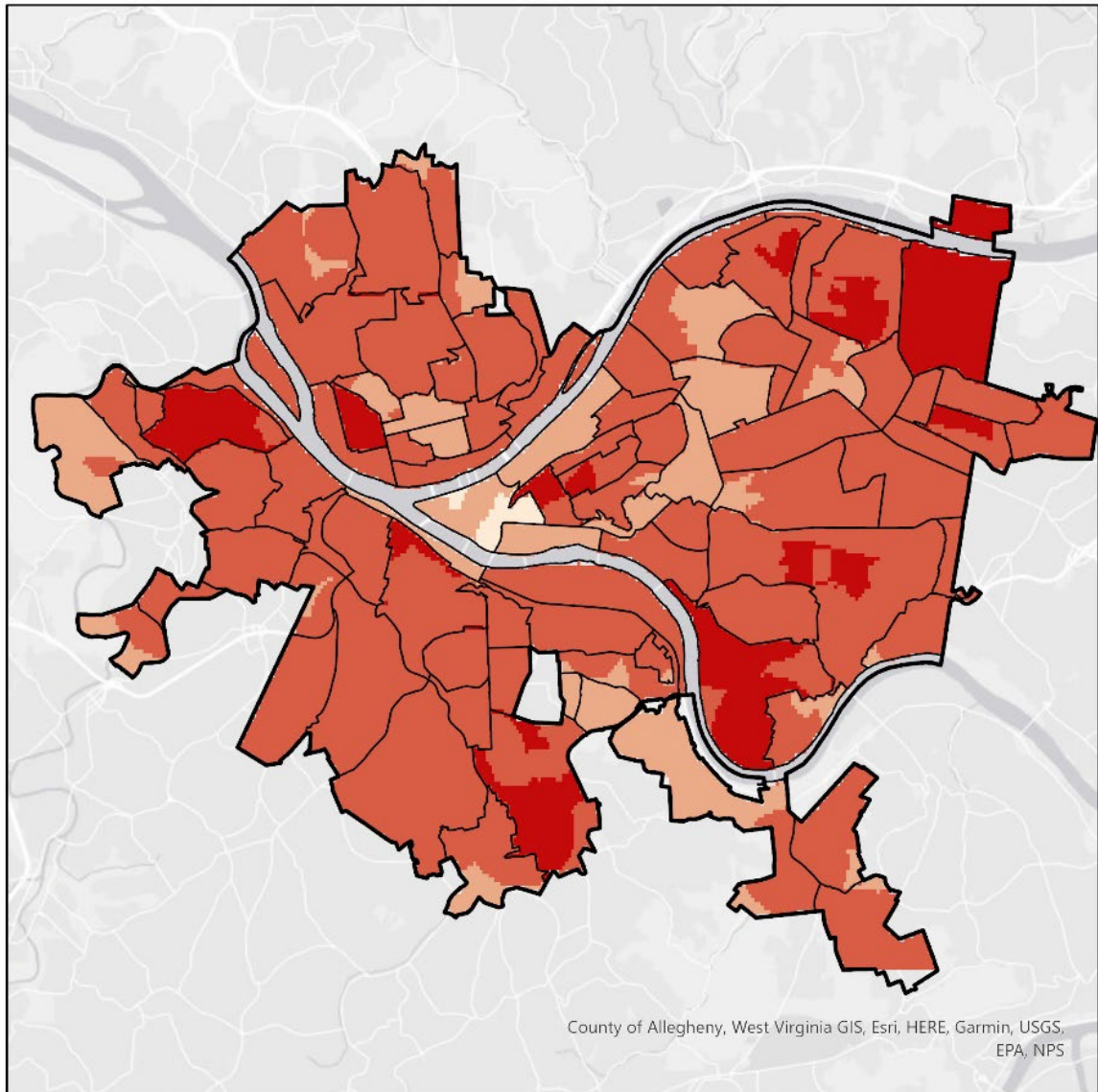


Figure 4.27: Potential Deconstruction Areas in Pittsburgh

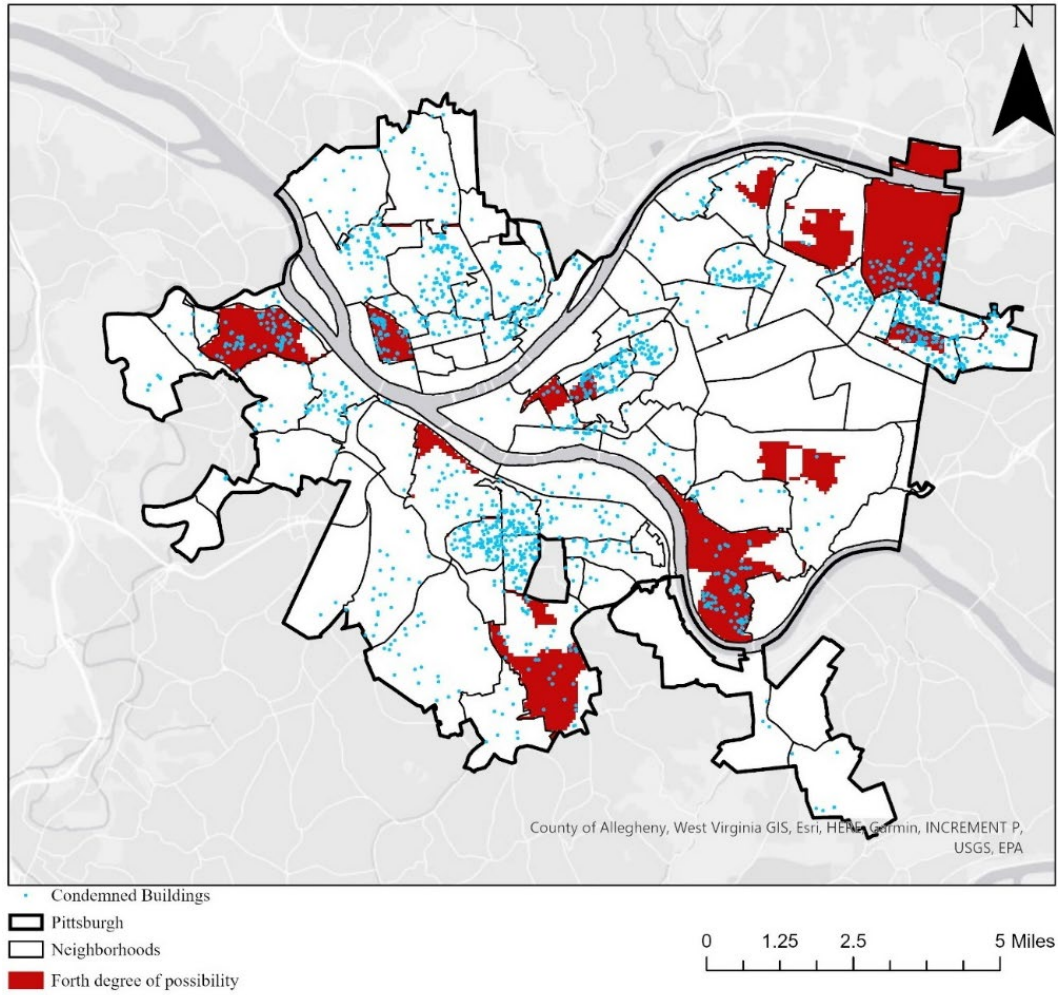


Figure 4.28: Differences between Possible Deconstructed Areas and the Distribution of Condemned Buildings

DISCUSSION AND SIGNIFICANCE

Discussion on the AHP Test and the Significance

The test in this paper is an experiment using AHP to make decisions. The relative weights of factors in the AHP model can be combined with other decision-making tools such as GIS analysis. However, the selection of factors and the calculation of weights need to be further demonstrated after the preliminary results are obtained so as to lay the foundation for the further optimization of the AHP model.

The selection of factors is the most important factor that impacts the results of AHP. Through the result of the test in this paper, a relative weight closer to one and zero means that the corresponding factors are extremely important and unimportant to deconstruction. **Figure 4.29** shows the relative weights integrated with the AHP model. The urban development factor in the economic criterion only has a relative weight of 0.08, and the building type criterion only has a relative weight of 0.12 compared with others. These factors with a low value of weights are extremely unimportant to deconstruction and can be removed from the AHP model or replaced by other potential factors to explore the influencing factors of deconstruction in the future entirely. Continuously optimize the AHP model and change factors through preliminary conclusions so that decision-makers can study the impact of more factors on deconstruction.

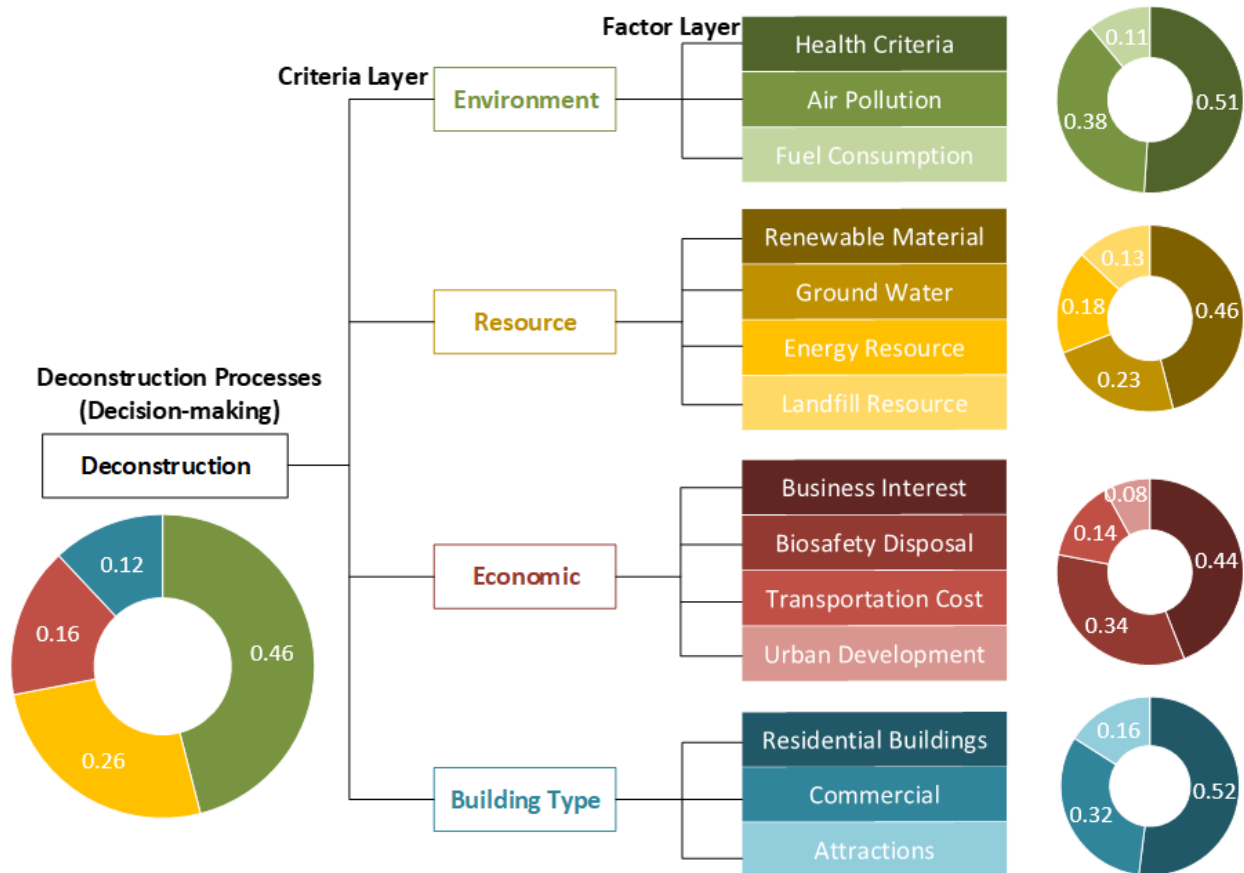


Figure 4.29: Relative Weights with AHP Model

Another advantage of AHP is that it can create multi-layer models. The test in this article creates a two-layer model, which clearly shows whether there is a correlation

between different factors. Simultaneously, it avoids asking experts to compare the importance of two unrelated factors. Creating a multi-layer model is crucial in AHP analysis. First, it saves data collection time because we don't need to compare all factors pairwise. In the semi-structured questionnaire, only six questions are needed to compare four factors, and 28 questions are needed to compare eight factors. Creating a reasonable hierarchical structure is one of the reasons why AHP analysis is convenient and quick. Second, this allows us to identify the relative importance of factors intuitively. When there are too many factors, it is difficult for us to analyze the influencing factors that are not the most important. Evans compared 28 factors simultaneously, which made his conclusion only focused on the four most important factors because the weights of the remaining factors were very similar (Evans et al. 2021). Therefore, controlling the number of factors at each layer allows us to analyze all factors more intuitively in the actual decision-making process.

The objectivity of AHP is one of its benefits. Although the subjective determinations of experts obtain the results of AHP, more experts will make the final result more objective and in line with the actual situation (Venkatesan 2019). **Table 4.8** shows some inconsistent results in this test through three experts. The inconsistency of experts' opinions is an objective reality because experts have their own focus areas for deconstruction, which has been explained in the Analytic Hierarchy Process section discussed earlier. However, the final relative weights are consistent with most experts and consider all of the opinions. Therefore, even if different experts have different opinions on which factor is the most important, the final result shows that the most important factors considered by these experts have higher weights. The AHP test in this paper confirms the relative objectivity of AHP, and the conclusion is presented based on all different points of view.

Table 4.8: Inconsistent Result through Three Experts

Criterion	Factors	Expert 1 Alicia Carberry	Expert 2 Terry Wiles	Expert 3 Sarah Kinter	Relative Weight
Environment	Health	0.20	0.61	0.71	0.51
	Air Pollution	0.70	0.29	0.14	0.38
	Recycle	0.57	0.48	0.32	0.46
Resource	Materials				
	Ground Water	0.18	0.12	0.37	0.23
Economy	Business	0.60	0.48	0.24	0.46
	Interest				
	Biosafety	0.22	0.20	0.57	0.23
Building Type	Disposal				
	Residential	0.28	0.63	0.63	0.52
	Commercial	0.58	0.10	0.25	0.32

Decision Making with the GIS Weighted Overlay

Weighted overlay through GIS analysis is a decision-making process using AHP conclusions. This paper combined different geodatabases and the related weight to find the target area for Pittsburgh Deconstruction Pilot Program. Several explanations and discussions about the result are discussed below.

The collection and utilization of data sets are the key factors affecting GIS decision-making. Considering the one-to-one correspondence between AHP factors and map layers will increase the difficulty of data set selection. This article did not find all the data sets for condemned buildings, which caused the final result to deviate from the

distribution of condemned buildings to a certain extent. When making actual decisions, using more specific information sources can effectively solve this problem and limit the scope to specific condemned buildings. However, this paper does come up with some conclusions from the potential deconstruction areas.

As shown in **Figure 4.28**, most of the potential targeted areas are located far from the center of the city when considering the weights of factors from this preliminary AHP analysis and the factor model from literature analysis. The distribution of these potential deconstruction projects is similar to the distribution of condemned buildings in Pittsburgh if considering not only the possible areas. **Figure 4.30** shows the relationship between the distribution of condemned buildings and the potential areas with each level. The two figures on the right in **Figure 4.30** consider both the third and fourth possibility levels of deconstruction activities. These areas contain most of the condemned buildings in Pittsburgh, which interprets the reliability of the test results in this paper.

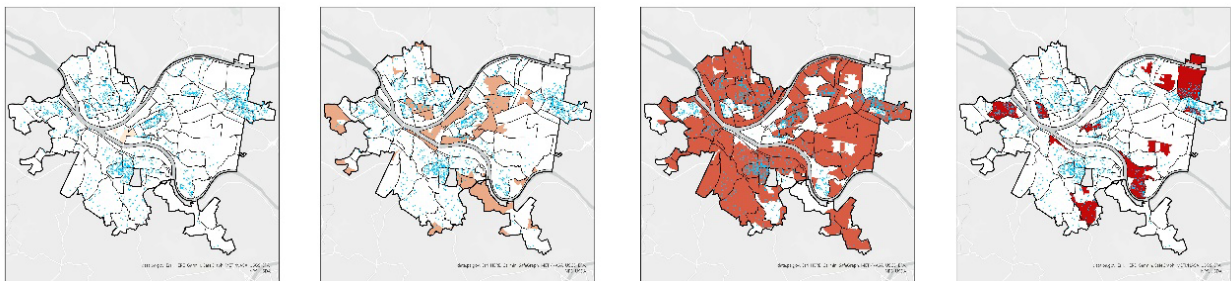


Figure 4.30: The Relationship between the Distribution of Condemned Buildings and the Potential Areas with Each Level

However, there are still processes worth optimizing. The final map made by weighted overlay verifies whether the factors in the AHP model meet the actual situation. Based on the five-level classification of each basic map related to each factor, the final map only shows four levels of possibility. The lack of the fifth level is that none of the census tracts or neighborhoods in Pittsburgh meet the best level of all the requirements from the four criteria in the AHP model. Hence, it means that either our selection of factors or our basic maps need to be optimized. This situation also interprets why some areas do not match the distribution of condemned buildings.

Another reason for those areas which are different from the distribution of condemned buildings may be caused by further consideration of other environment, resources, and economic factors. **Figure 4.31** to **Figure 4.34** shows the relationship of condemned buildings and the potential deconstruction areas only considering one criterion. Areas with the highest two levels of possibility are selected in these maps. Highland Park is recognized as the best neighborhood for deconstruction, considering the environment even though there are less condemned buildings. Neighborhoods with a large number of condemned buildings do not satisfy the best deconstruction environment. Apart from the reasons discussed above, less consideration of other environmental factors also impacts the result. **Figure 4.32** shows that the result meets the distribution of condemned buildings well. However, same as the environment criterion map, the maps of the economy and building types (**Figure 4.33** and **Figure 4.34**) show the inconsistency, which shows that our model lacks consideration of other factors. Also, the inaccurate results only considering one criterion confirm that deconstruction decision-making requires multiple factors simultaneously.

The social criteria focused on social justice is also affecting the condition of condemned buildings with the contribution of other categories. These social factors are

fully discussed in Alyssa Mayorga’s research and are a great supplement to the AHP model in this paper.

In summary, the GIS analysis based on the result from the AHP model confirms the following points. The deconstruction decision-making requires consideration of multi-layer factors, and our two-layer model works well to a certain degree. Based on the above findings and discussions about the AHP test, there are some recommendations for the Deconstruction Pilot Program in Pittsburgh. The program should focus on areas far from the city center where condemned buildings have a higher potential for deconstruction. Also, further considerations of other factors should be considered for finding the best deconstruction properties. However, there are some inconsistent areas attributed to the lack of other factors and imprecise data sets. With the improvement of the test of this paper, the result should be more accurate.

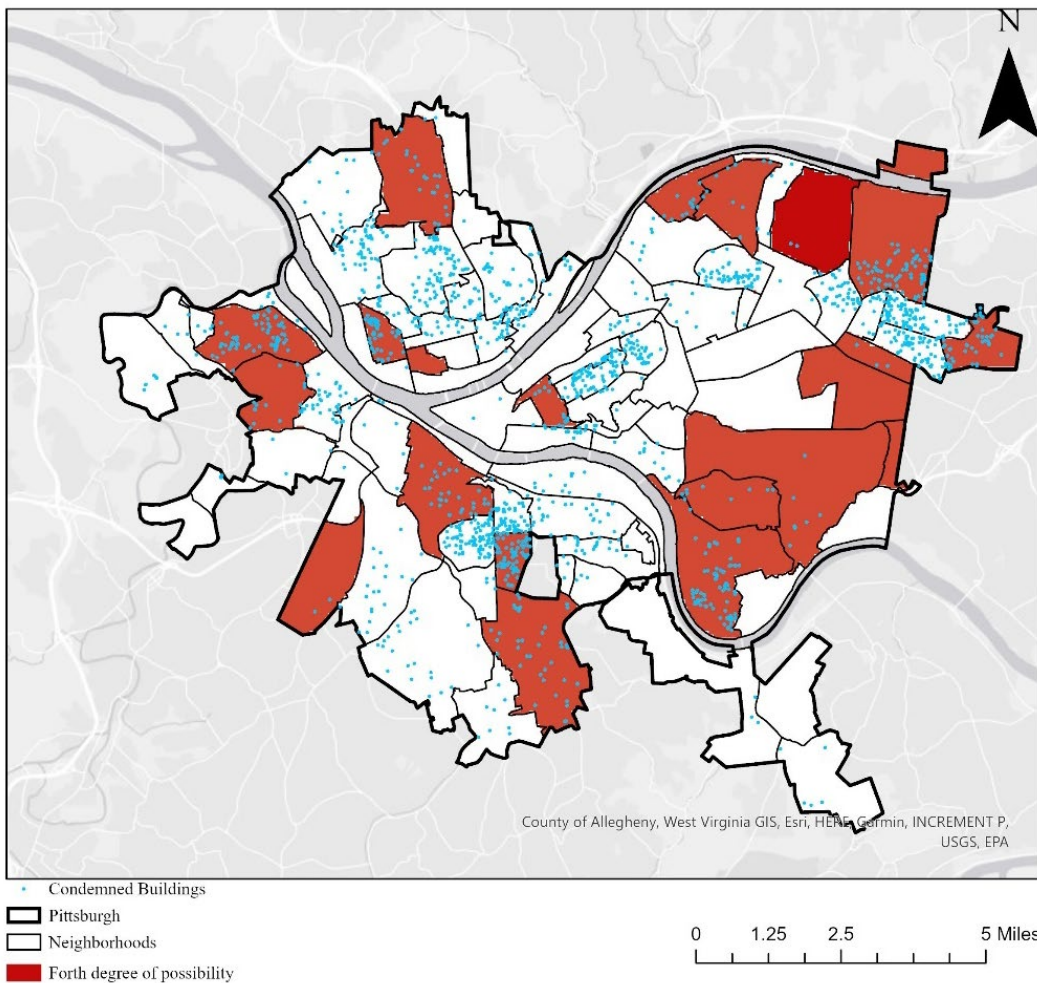


Figure 4.31: Differences between Possible Deconstructed Areas Only Considering Environmental Factors and the Distribution of Condemned Buildings

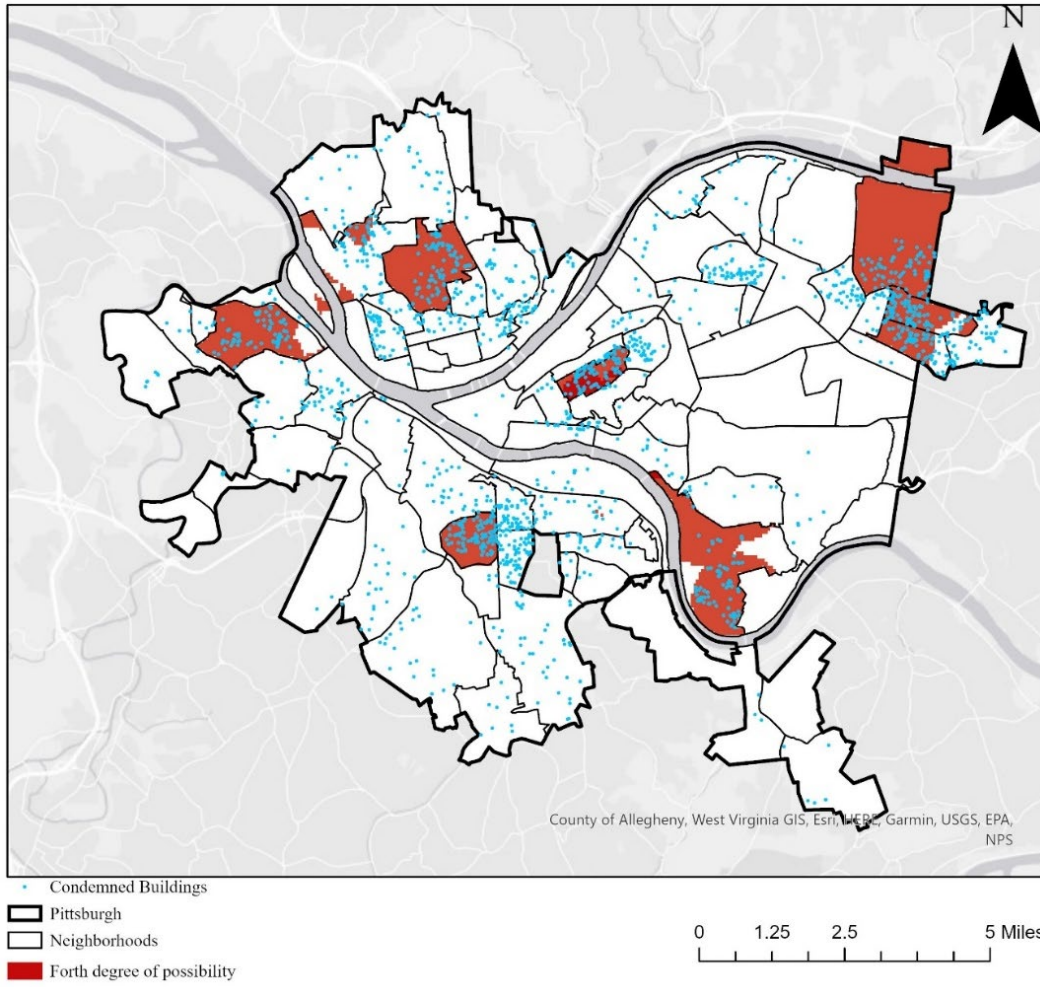


Figure 4.32: Differences between Possible Deconstructed Areas Only Considering *Resource Factors* and the Distribution of Condemned Buildings

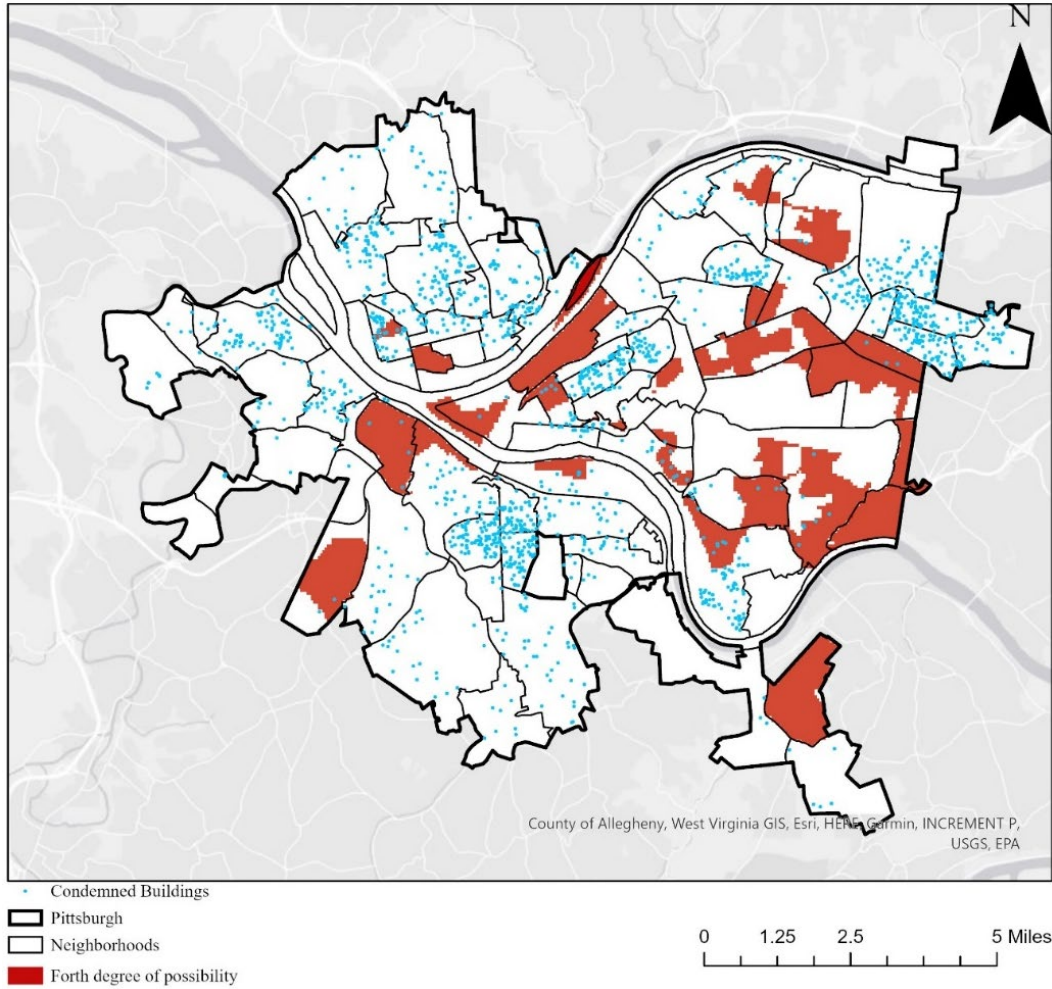


Figure 4.33: Differences between Possible Deconstructed Areas Only Considering *Economic Factors* and the Distribution of Condemned Buildings

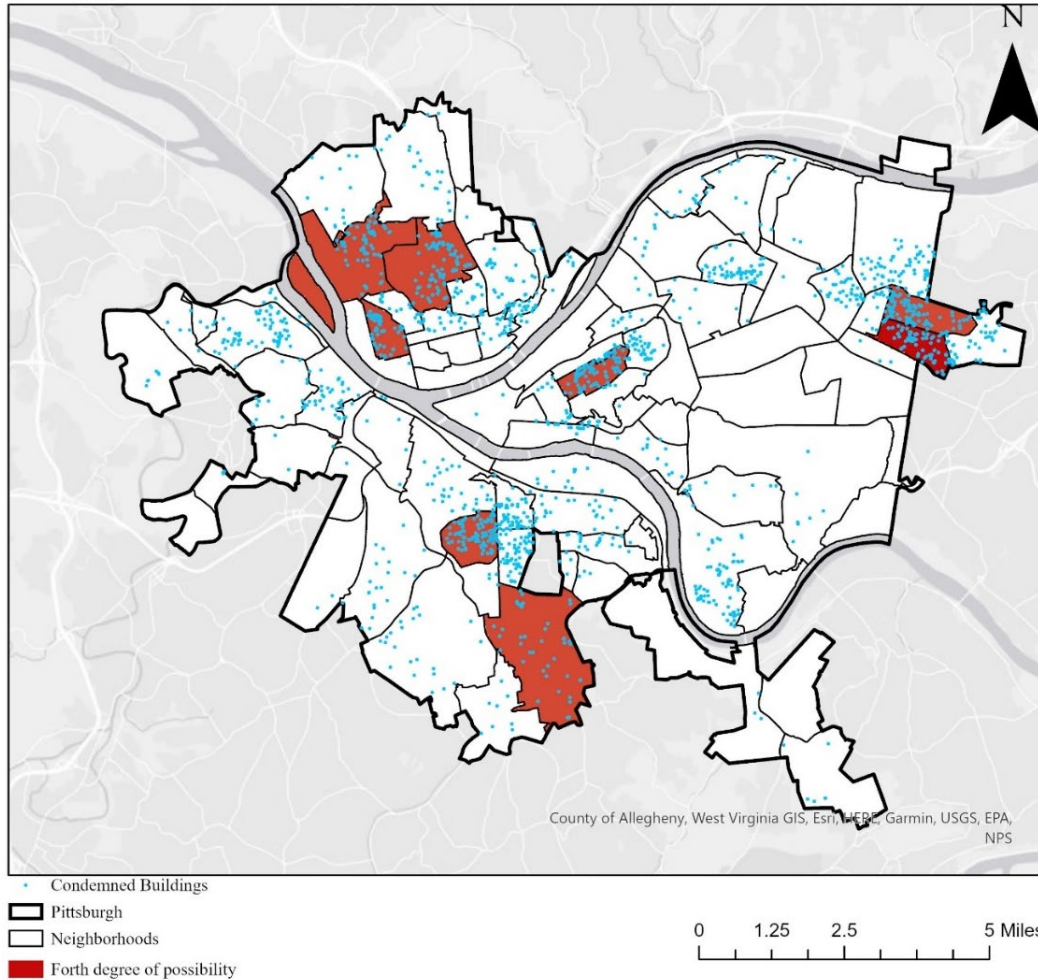


Figure 4.34: Differences between Possible Deconstructed Areas Only Considering *Building Type Factors* and the Distribution of Condemned Buildings

Recommendations for Making Decisions Using AHP

The advantages of the AHP process are discussed above. Overall, the huge advantages are the reason why AHP is a powerful tool for decision-makers. In summary, AHP can help make decisions comprehensively, as it can sort out a great factor model with multi-layers. With the pairwise contrast and short time semi-structured interview and questionnaire survey, it is objective, flexible, and simple for decision-makers to apply it to other decision-making processes. With more experts and stakeholders participating in this process, the constantly updated results make decision-makers critical think about the factors they chose and the opinions they made. By integrating all the opinions together, decision-makers don't need to worry that the results be transferred to the interests of a certain team. The final result will balance the competing interests of all stakeholders, as discussed in the *Discussion on the AHP Test and the Significance* section.

Limitations and Future Work

Before applying this work to targeted deconstruction areas of Pittsburgh, there are some limitations for our work that should be considered. Apart from the limitations of the AHP model itself and the GIS analysis discussed in chapter six, there are still four limitations for using AHP to make decisions in this paper. First, this test is lacking more experts with different perspectives. If this work were to serve a real decision-making project, then we need a larger sample and more than ten experts with different professions to meet this condition. Second, we lack diverse feedback. We hope that this model can be applied to different stakeholders such as the municipal government, owners, contractors, designers, etc. Therefore, diverse feedback will help us obtain rankings of different factors and serve different teams. Third, based on the above analysis, we lack AHP templates for different stakeholders. Fourth, this research is only a preliminary application of AHP to demonstrate the process. A social survey and structured interview are needed. Therefore, this study lacks a more extensive factor identification, ignoring the important attribute of social factors. For different criteria, this study also lacks a more detailed factor classification.

In order to supplement the above shortcomings, this research will focus on the following points in the future. First, based on the preliminary conclusions obtained in this research, the AHP model is further optimized. Second, based on the optimized AHP model, we conduct a wider range of questionnaire surveys to consolidate our weighting conclusions. Third, under the new weight distribution conditions, obtain the distribution of the best-deconstructed properties and conduct actual investigations. Through actual research, we will clarify a series of deconstruction projects that are environmentally friendly, resource-friendly, lower cost, and higher profit. When a large number of 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. When reclassifying properties, the large number of commercial condemned buildings should be considered more carefully. Based on the discussion in the *Importance of Influencing Building Type Factors with AHP Analysis* section, a large number of special materials and components in commercial buildings have great value in reuse and recycling.

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CHAPTER 4 APPENDIX

AHP Questionnaire on the Factors Affecting the Deconstruction Process

My name is Zehan Zhang and I am a graduate student in Master of Science in Architecture-Engineering-Construction Management program at Carnegie Mellon University. I am researching the most significant factors influencing the whole deconstruction process. This research has produced an evaluation system that focuses on four potential influencing criteria below and hopes to determine the importance of influencing factors through the ratings of experts in different fields.

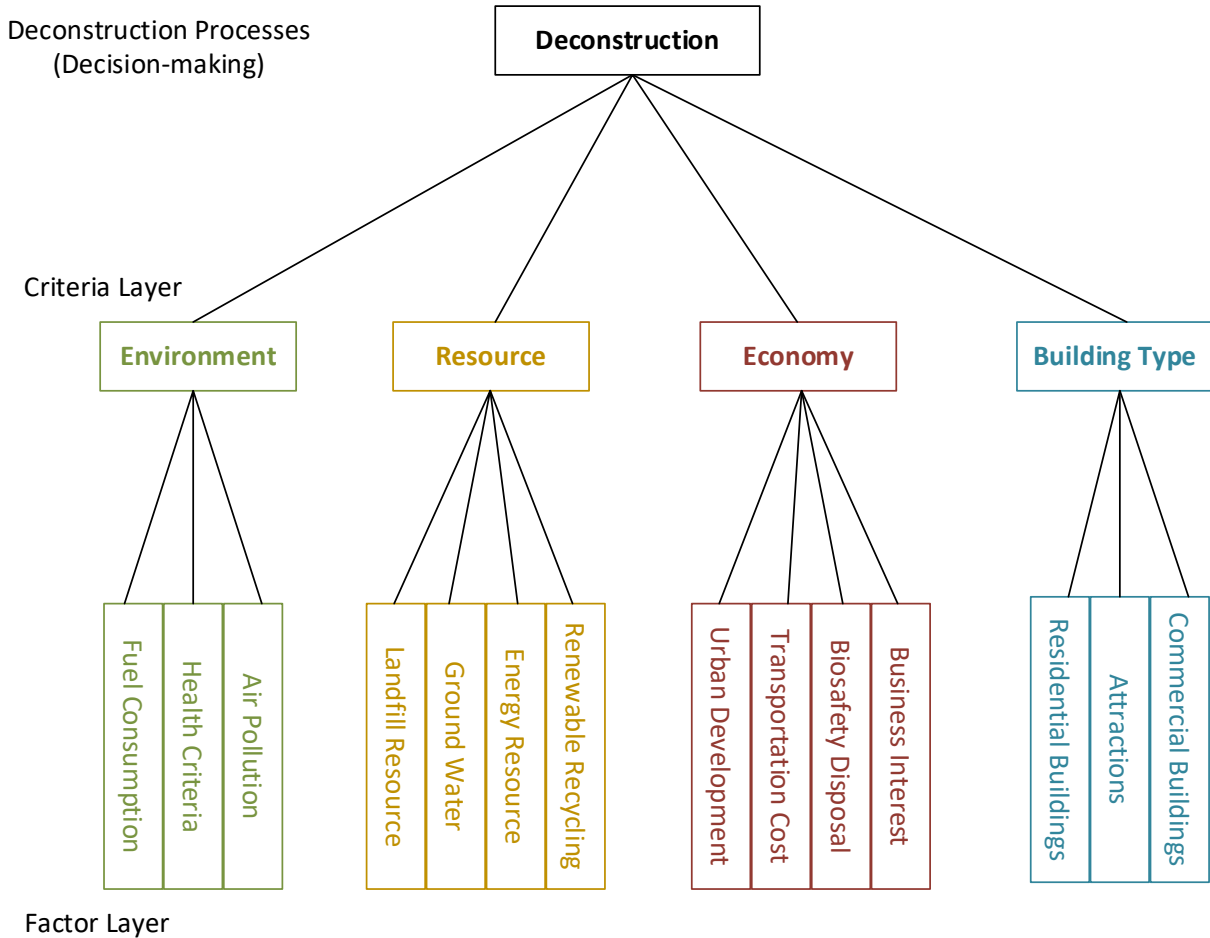


Figure 1: Deconstruction evaluation system model

Questionnaire Instructions

The purpose of these questions is to determine the relative weights of different influencing factors and is designed according to the Analytic Hierarchy Process (AHP). For each question you will be asked to compare the relative importance of **factor [A]** to **factor [B]**. There are the following 5 levels as shown below.


Extremely unimportant 1/5	Slightly unimportant 1/3	Equally important 1	Slightly important 3	Extremely important 5
------------------------------	-----------------------------	------------------------	-------------------------	--------------------------

Questions:

For environmental criteria:


Regarding **fossil fuel consumption**, what is the relative importance of **health impacts**?

Extremely unimportant	Slightly unimportant	Equally important	Slightly important	Extremely important
1/5	1/3	1	3	5




Regarding **fossil fuel consumption**, what is the relative importance of **air pollution**?

Extremely unimportant	Slightly unimportant	Equally important	Slightly important	Extremely important
1/5	1/3	1	3	5



Regarding **health impact**, what is the relative importance of **air pollution**?


Extremely unimportant	Slightly unimportant	Equally important	Slightly important	Extremely important
1/5	1/3	1	3	5



For resource criteria:


Regarding **landfill resource**, what is the relative importance of **ground water resource**?

Extremely unimportant	Slightly unimportant	Equally important	Slightly important	Extremely important
1/5	1/3	1	3	5




Regarding **landfill resource**, what is the relative importance of **energy resource**?

Extremely unimportant	Slightly unimportant	Equally important	Slightly important	Extremely important
1/5	1/3	1	3	5




Regarding **landfill resources**, what is the relative importance of **renewable and recycle Material**?

Extremely unimportant	Slightly unimportant	Equally important	Slightly important	Extremely important
1/5	1/3	1	3	5




Regarding **ground water resource**, what is the relative importance of **energy resource**?

Extremely unimportant	Slightly unimportant	Equally important	Slightly important	Extremely important
1/5	1/3	1	3	5




Regarding **ground water**, what is the relative importance of **renewable and recycle Material**?

Extremely unimportant	Slightly unimportant	Equally important	Slightly important	Extremely important
1/5	1/3	1	3	5



Regarding **energy resource**, what is the relative importance of **renewable and recycle Material**?

Extremely unimportant	Slightly unimportant	Equally important	Slightly important	Extremely important
1/5	1/3	1	3	5



For economic criteria:

Regarding **urban development**, what is the relative importance of **transportation cost**?

Extremely unimportant	Slightly unimportant	Equally important	Slightly important	Extremely important
1/5	1/3	1	3	5

Regarding **urban development**, what is the relative importance of **biosafety disposal cost**?

Extremely unimportant	Slightly unimportant	Equally important	Slightly important	Extremely important
1/5	1/3	1	3	5

Regarding **urban development**, what is the relative importance of **business interest**?

Extremely unimportant	Slightly unimportant	Equally important	Slightly important	Extremely important
1/5	1/3	1	3	5

Regarding **transportation cost**, what is the relative importance of **biosafety disposal cost**?

Extremely unimportant	Slightly unimportant	Equally important	Slightly important	Extremely important
1/5	1/3	1	3	5

Regarding **transportation cost**, what is the relative importance of **business interest**?

Extremely unimportant	Slightly unimportant	Equally important	Slightly important	Extremely important
1/5	1/3	1	3	5

Regarding **biosafety disposal cost**, what is the relative importance of **business interest**?

Extremely unimportant	Slightly unimportant	Equally important	Slightly important	Extremely important
1/5	1/3	1	3	5

For Building Type criteria:

Regarding **residential buildings**, what is the relative importance of **commercial buildings**?

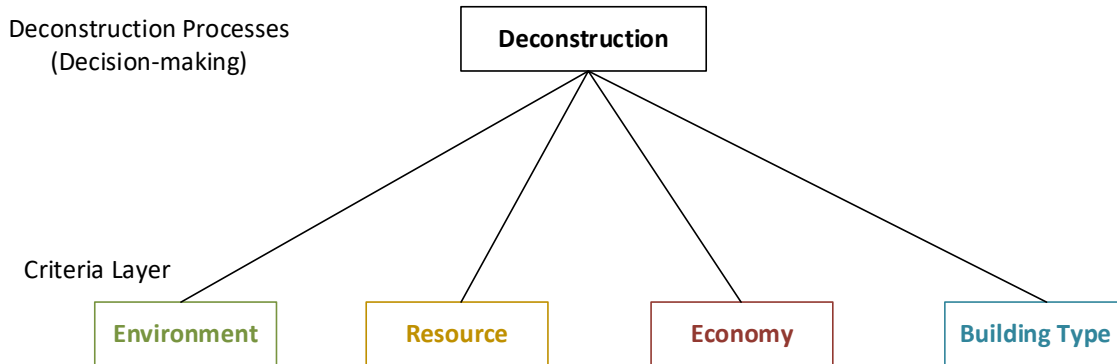
Extremely unimportant	Slightly unimportant	Equally important	Slightly important	Extremely important
1/5	1/3	1	3	5

Regarding **residential buildings**, what is the relative importance of **attractions**?

Extremely unimportant	Slightly unimportant	Equally important	Slightly important	Extremely important
1/5	1/3	1	3	5

Regarding **commercial buildings**, what is the relative importance of **attractions**?

Extremely unimportant	Slightly unimportant	Equally important	Slightly important	Extremely important
1/5	1/3	1	3	5



For the deconstruction process, comparing these criteria:

Regarding the **environment**, what is the relative importance of **resource**?

Extremely unimportant	Slightly unimportant	Equally important	Slightly important	Extremely important
1/5	1/3	1	3	5

Regarding the **environment**, what is the relative importance of **economy**?

Extremely unimportant	Slightly unimportant	Equally important	Slightly important	Extremely important
1/5	1/3	1	3	5

Regarding the **environment**, what is the relative importance of **building type**?

Extremely unimportant	Slightly unimportant	Equally important	Slightly important	Extremely important
1/5	1/3	1	3	5

Regarding **resources**, what is the relative importance of **economy**?

Extremely unimportant	Slightly unimportant	Equally important	Slightly important	Extremely important
1/5	1/3	1	3	5

Regarding **resources**, what is the relative importance of **building type**?

Extremely unimportant	Slightly unimportant	Equally important	Slightly important	Extremely important
1/5	1/3	1	3	5

Regarding the **economy**, what is the relative importance of **building type**?

Extremely unimportant	Slightly unimportant	Equally important	Slightly important	Extremely important
1/5	1/3	1	3	5

CHAPTER 5 - FACTORS AFFECTING THE COST OF DECONSTRUCTION PROJECTS IN THE PITTSBURGH AREA

ZHIHAN FU

ABSTRACT

Many U.S. cities suffer from a wide range of vacant and abandoned residential, commercial, and industrial properties. Statistics shows that approximately 10.7% of the housing units in the United States were vacant (US Census). This building abandonment issue can bring negative economic, social, and environmental consequences to urban areas. Demolition is the default and prevalent solution to address these issues while leading to significant environmental, economic, and social costs, and generating large amounts of construction and demolition (C&D) debris. By contrast, deconstruction is a more sustainable method of systematically dismantling buildings that can recover more than 80% of the material for reuse and recycling (Tatiya et al. 2018).

Typically, the cost decision method for deconstruction is simply calculated by adding disposal cost, equipment cost, material cost, labor cost, and other minor costs such as permitting and testing (Dantata, Touran, and Wang 2005). However, the factors that affect the cost of deconstruction are more complicated, so the previous method of forecasting costs is not comprehensive or accurate enough for wise decision-making. To improve the cost prediction of deconstruction, cost prediction models such as case-based reasoning (CBR) models based on machine learning are proposed in this study. Defining predictors and the weights of each predictor are critical first steps. Therefore, this study seeks to extract and weigh the relative importance of relevant criteria related to deconstruction by using Analytic Hierarchy Process (AHP). To do this, I extracted initial criteria by reviewing previous studies and adjusted them according to several experts' opinions, including an experienced deconstruction estimator and project managers. I then determined the relative importance of these criteria through pairwise comparisons

at each level of the hierarchy. The information given by several experts yields the averaged AHP weights of each criterion, which shows that building materials, design complexity, and building story affect the cost of deconstruction most. Building age has a relatively minor influence on price. These results can help decision-makers consider how to apply the weighting of these influencing factors to real deconstruction cases to improve deconstruction cost prediction models. The weights of these criteria can be used as the coefficients of the various factors in the cost prediction model formula (Tatiya et al. 2018).

INTRODUCTION

Data shows that the number of vacant homes in the United States reached a record high of over 17 million in 2019.¹ This data indicates that the abandonment of property and structures in commercial and residential buildings is becoming increasingly problematic. As the number of abandoned buildings grows, problems such as government intervention, funding for demolition projects, and the massive waste stream generated by the demolition of these buildings have also arisen (Zahir et al., 2016).

A recent report from the US EPA Office of Resource Conservation and Recovery classified the types of materials found in construction and demolition (C&D) debris data from 2012 to 2015 (US EPA 2018). Enumerating the changing trends of various types of waste in the past few years, and the relationship between these changing trends and construction activities, it was estimated that 169,161,000 tons of construction waste is mainly related to building demolition. Data revealed another increasing trend for nearly every material in terms of total debris generation from 2012 to 2015. Furthermore, demolition activities contributed to more than 90% of debris generation for each material associated with C&D activities, except for drywall and plasters in which demolition accounted for slightly more than 80%. This data can provide a foundation for the future direction of construction engineering management and indicates that deconstruction is a better option to reduce construction waste in the construction cycle.

Pittsburgh currently has more than 1,700 buildings condemned as uninhabitable and the current demolition process is expensive and environmentally hazardous (City of Pittsburgh 2021). Compared to demolition, deconstruction is a more sustainable approach that can reduce waste, improve public health outcomes, and provide economic benefit to communities. Therefore, on April 20, 2021, Mayor William Peduto issued an Executive Order for the City of Pittsburgh “to develop a unified City-led deconstruction policy and establish a city-led pilot program utilizing deconstruction methods on City-owned condemned properties” (City of Pittsburgh 2021).

Since this deconstruction policy in the Pittsburgh area has only recently been proposed, the current deconstruction projects in the Pittsburgh area are mainly carried out by private organizations. For construction projects, the increased cost is a common concern that prevents decision-makers from implementing deconstruction and is also the primary consideration.

Typically, the cost decision method for deconstruction and demolition is simply calculated by adding disposal cost, equipment cost, material cost, labor cost, and other minor costs such as permitting and testing (Dantata, Touran, and Wang 2005). However, the factors that affect the cost of deconstruction are more complicated, so the previous method of forecasting costs is not comprehensive or accurate enough for wise decision-making. Also, since deconstruction and demolition are methodically different, the previous cost prediction method may result in inaccurate and contradictory predictions. This indicates a need for a unique impact factor and cost forecasting method for deconstruction. To address this gap, prediction cost models based on machine learning for deconstruction projects are proposed, where defining predictors and weights of each predictor are critical steps in these models. The following sections in the report are mainly organized by define the determining criteria for deconstruction cost and then defining the weights of each criteria using AHP method.

Typically, the cost decision method for deconstruction and demolition is simply calculated by adding disposal cost, equipment cost, material cost, labor cost, and other minor costs such as permitting and testing, but may result in inaccurate and contradictory predictions.

LITERATURE REVIEW

Background

Currently, many American cities suffer from a wide range of vacant and abandoned residential, commercial, and industrial properties caused by the economic recession. This building abandonment problem can bring negative economic, social, and environmental consequences to urban areas. Demolition and landfiling are standard methods of removing these wastes but generate large amounts of C&D debris. Deconstruction is a more sustainable method of systematically dismantling buildings, achieving more than 80% of the material reuse and recycling (Tatiya et al. 2018). However, the increase in costs due to deconstruction is a common problem that hinders decision-makers from implementing deconstruction mandates or policies. There have been a variety of methods to calculate the cost and duration of deconstruction. In previous years, the main calculation method is adding disposal cost, equipment cost, material cost, labor cost and other costs such as permitting and testing (Dantata, Touran, and Wang 2005).

However, as the factors that affect the cost of demolition and deconstruction become more and more complicated, the previous method of forecasting demolition and

destruction costs lacks comprehensive consideration and is not accurate enough. Therefore, with the development of Artificial Intelligence and Machine Learning technology, an increasing amount of studies have selected various possible cost determinants in case of studies, focusing on complex cost prediction models and then using machine learning algorithms to solve these problems. Models generally use AHP to determine the composite weight of the decision elements using pairwise comparison at each level of the hierarchy (An, Kim, and Kang 2007).

Cost Prediction Models

In establishing the deconstruction cost prediction model, the key is to extract the initial predictor and determine the weight of the predictor. The existing cost models start from the following significant factors: construction type, building materials, location, scale, region, and schedule of previous projects, etc., and then extract minor determinants from them. Research also refers to the existing CBR cost prediction model and deconstruction evaluation tool (An, Kim, and Kang 2007) to extract initial predictive factors.

For the determination of the weight, the AHP analysis method is used. Most of the previous studies collected AHP data through structured interviews with deconstruction experts including the experienced deconstruction estimator and project managers (Tatiya et al. 2018). There are many methods to determine the weights of predictors. First, AHP determines the relative importance of a variable through pairwise comparisons² of all variables, and the specific implementation method is to construct an AHP matrix to compare the factors in pairs, use specific numbers to measure the importance of the factors, and finally take the average value for each factor. Previous research has shown that Building conditions (BC) and Building area (AR) have the highest weights (Tatiya et al. 2018). Other methods are proposed to determine the weight of the impact factor.

According to earlier research, region, building category, and public-private nature will significantly impact deconstruction and demolition (Chen and Lu 2017). The research tests the factors accordingly. When the n th category is tested as an influencing factor, the other $n-1$ variables are used as explanatory variables. Then we perform a linear regression analysis on the selected factors and the cost or duration of demolition and deconstruction and calculate the R Square and P-value. These two values show the correlation between the selected variables and demolition and deconstruction. The

² Pairwise comparisons judge the preference of one factor to another. This can be done systematically to establish preferences among many factors through a series of comparisons.

closer the correlation between a variable and demolition and deconstruction, the greater the weight of the variable as a predictor.

Building materials are an essential influencing factor Akanbi et al. (2019) that support for disassembly and deconstruction based on end-of-life evaluation is reduced in the following order: building with steel structure, timber structure, concrete structure (Akanbi et al. 2019). The researchers used Disassembly and Deconstruction Analytics System (D-DAS) and Revit to evaluate how these building materials affect the deconstruction (Akinade et al. 2015).

Gap

Many factors need to be considered in real deconstruction projects, and previous studies mainly focused on just one or two factors separately. Merely describing the importance of some impact factors at the literal level is insufficient for forecasting models and cost calculations. So, we need to analyze the impact of these factors as a whole and quantifying the impact of all these factors can facilitate future applications. Therefore, the method I consider is to calculate the weight of each factor.

PROBLEM STATEMENT (GAP) AND RESEARCH QUESTION(S)

Problem Statement

According to the literature review, different building materials, building types, regions and some other factors have a great impact on deconstruction cost. To incorporate these impact factors into the deconstruction prediction model, we need to quantify the impact of different factors by calculating the weight of each impact factor. We can then use this weight as a coefficient of the cost prediction model to convert the literal impact level into a number multiplying with input value in the cost prediction models. Moreover, the previous literature mainly considers influencing factors from an academic perspective, but to apply those factors to the real deconstruction case, I selected and analyzed factors that need to be considered in architectural deconstruction projects.

Research Questions

1. What criteria affect the cost of deconstruction projects the most?

To figure out the answer for this question, I divided this question into three sub questions, and elaborated on the specific solution in the next methodology section.

Sub Questions:

- 1.1. How can we extract the main criteria affecting the deconstruction cost?
- 1.2. How to collect data for AHP calculation?

1.3. How to determine the relative importance of all these criteria?

2. How do these factor weights affect the cost of real deconstruction projects?

METHODOLOGY AND METHODS

The main criteria for the first research question were selected through previous literature. To confirm the weights of these criteria, I collected professional evaluations of these factors and related data used in the AHP method through online interviews with experts experienced in deconstruction projects. Next, the AHP matrix method was applied to calculate the weight of each criterion and then Control Variable Method is used to determine how these criteria affect the deconstruction cost.

Criteria

To extract the main criteria affecting the deconstruction cost, I selected the initial criteria by reviewing previous literature and adjusted them according to local AEC professionals' suggestions. The cost decision of a deconstructed project is far more than just a few factors that are linearly related. Many factors will have a complex impact on the cost, which may also affect each other. In addition to the factors like building materials, types and regions mentioned above, nine criteria are extracted as predictors. I then performed an analytical hierarchy process (AHP) analysis to calculate their weights. Here lists those criteria and the descriptions (Tatiya et al. 2018).

Table 5.1: The Nine Criteria and their Descriptions

Item	Description
Building age (BA)	Range between the times of built and deconstructed.
Building conditions (BC)	A larger percentage means better conditions, e.g., water/fire damages and holes in structure.
Building area (AR)	Building size affects the use of equipment and safety precautions.
Building story (BS)	The number of floors directly affects structure, safety, and labor for removal.
Building materials (BM)	Composition of building materials, such as: steel bar, cement, concrete, wood.
Hazardous materials (HM)	High means large amounts of hazardous materials.
Geographical location (GL)	Good indicates low labor, equipment and dumping cost, and vice versa.
Regional policy (RP)	Regional policy for deconstruction in Pittsburgh
Design complexity (DC)	High means complicated design, indicating intensive labor for removal, and vice versa.

AHP Method

The AHP analysis method produces a matrix of the relative importance of variables through pairwise comparisons (An, Kim, and Kang 2007b). I generally use this method to determine the combined weight of the decision criterion using pairwise comparison at each level of the hierarchy.

The essence of the AHP method is to construct a matrix expressing the relative values of a set of attributes. Pairwise comparisons are carried out for all factors to be considered, then fill in the numbers according to the difference in importance between the two factors to the AHP matrix. The larger the number, the more significant the difference in importance between the two factors. (Geoff Coyle 2004)

The next step is to calculate a list of the relative weights, importance, or value, of the factors based on this AHP matrix, referring to the knowledge of linear algebra. This part of the calculation is done directly with *Python* (an interpreted high-level, general-purpose programming language) or *Excel*.

Online Interview

AHP data was collected through structured interviews with deconstruction experts, including experienced project managers and design for deconstruction (DfD) experts. An online interview with two project managers experienced in deconstruction projects was conducted. The project managers included Dave Bennink of Building Deconstruction Institute and Terry Wiles from Construction Junction which is located in Pittsburgh area. Both gave detailed descriptions of the specific impact of each factor on the deconstruction cost based on their rich personal experiences with deconstruction. Additionally, they assigned numbers for each factor according to its effectiveness towards deconstruction cost, which aided in populating the AHP matrix.

AHP Matrix

As mentioned above, each expert performed the pairwise comparison for those 9 criteria and assigned numbers for each comparison based on the importance for deconstruction cost of each pair factors to fill out the AHP matrix. For example, imagine if we were to compare two factors such as Building Condition (BC) and Building Age (BA). If the factor BC affects the price more than BA, we might assign number 1 to BA, and then according to the greater influence of BC than BA, assign a number between 2-9 to BC, the greater the impact of BC on deconstruction cost, the greater the number that would be assigned. If BC and BA have the same effect, then assign 1 in the matrix.

After filling out the AHP matrix, I used *Python* and *Excel* to calculate the weights of each factor and perform the consistency test.

Control Variable Method

To show the specific impact of the weight of these criteria on the cost of the deconstruction project, based on the weights of each criterion I calculated, I used the **Controlled Variable Method** for comparison.

Based on data from the case study, two buildings are used for comparison, one for the control case and one for the experimental case. The variables in the control case remain unchanged, and each group only changes the data of one variable in the experimental case. Then I compared the corresponding changes in the deconstruction cost of the experimental case caused by the change of this variable data in each group. By analyzing the relationship between the percentage change of each component cost and the weight of the changed factors of the group, it can be determined how the weight factors I have derived will impact pricing.

FINDINGS

Expert Interview with Dave Bennink

The first expert, Dave Bennink, has been involved in deconstruction projects across the U.S. Thus, the results he gave are more broadly relevant across cities. Instead of using AHP matrix, he used the sequential ranking and assigned the scores for each criterion according to its effectiveness and provided important insights.

a) Description of each factor

Table 5.2: The Nine Criteria and their Descriptions from Dave Bennink

Item	Description
Building age (BA)	Old buildings with high quality building materials reduce the cost and duration of deconstruction.
Building conditions (BC)	BC is one of the most important factors that directly determines the difficulty and cost of deconstruction.
Building area (AR)	The project would not be 100 times harder when the building size get 100 times larger. The bigger the building, the deconstruction technically gets easier.
Building materials (BM)	The more valuable materials that are in the buildings, the less expensive the job gets.
Hazardous materials (HM)	The more HM there are, the worse it gets, and the more expensive the project gets. Most HMs cancel out with demolition approach.
Geographical location (GL)	Low labor, equipment, and dumping cost leads to low deconstruction cost.
Regional policy (RP)	As the city promotes deconstruction, the deconstruction price rises.
Design complexity (DC) & Building story (BS)	Deconstruction techniques are different with different building heights. Buildings with more than four stories require a crane. Buildings with less than three stories require different methods from the ground.

b) Weights calculation

The following table lists the scores given by Dave that I converted to weights of each factor according to this formula.

W_i represents the weight of the i factor.

$$\sum_{i=1}^9 W_i = 1$$

Table 5.3: Scores for All Criteria According to Dave Bennick

Criterion	Score
Hazardous materials(HM)	3
Design complexity(DC)	7
Geographical location(GL)	4
Building story(BS)	5
Building conditions(BC)	8
Building materials(BM)	9
Regional policy(RP)	6
Building area(AR)	2
Building age(BA)	1



The following bar chart intuitively shows the weights of each criterion sequentially.

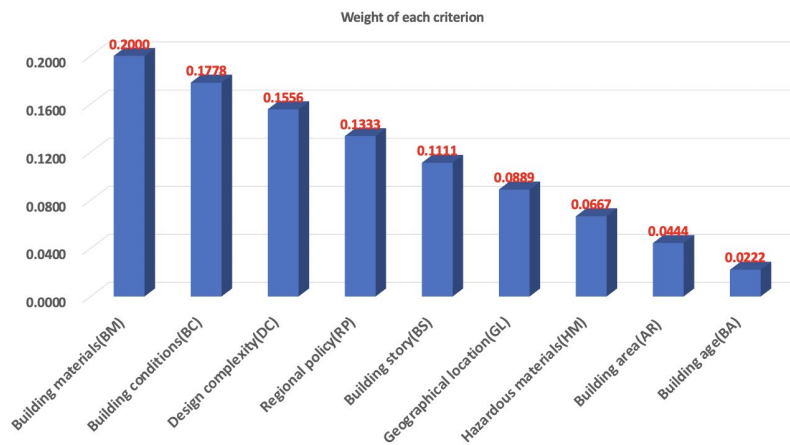


Figure 5.1: Weight for Each Criterion According to Dave Bennick

According to Dave, building materials affects cost most and building age has the least impact.

Expert interview with Terry Wiles

For a Pittsburgh area perspective, I interviewed Terry Wiles, an experienced project manager at Construction Junction in Pittsburgh. His opinions are very helpful and more representative for Pittsburgh. He described the impact of each criterion in detail and assigned a number to each pairwise comparison. Then I filled out the AHP matrix to calculate the weight of each factor.

a) Description of each factor

Firstly, the following describes each criterion's effectiveness to deconstruction cost from Terry's perspective.

Table 5.4: The Nine Criteria and their Descriptions from Terry Wiles

Items	Description
Building age (BA)	It's not necessarily a cost factor. The newer the building is, it obviously may have more stuff in it. The older the building is, the better the quality of material there, and the more accessible it can break down.
Building conditions (BC)	Building condition is a determining evaluator on whether the building is suitable for deconstruction and is not necessarily an issue on the deconstruction cost.
Building area (AR)	No matter where you do the deconstruction project, you need a large area to place disassembled materials, or it will cost you much to find a place to deposit those materials and process them. So, the building area also affects the price.
Building materials (BM)	The more valuable materials that are in the buildings, the less expensive the job gets.
Hazardous materials (HM)	In looking at the cost, the effectiveness of hazardous materials is vast. Because of its effects, there is a lot of mediation, which obviously increases the cost.
Geographical location (GL)	The closer they are to the building location, the less labor cost for them to get the materials and take them back. If geographical location is increasing the cost, then the building materials there will be high value for them to make sense to go and get them.
Regional policy (RP)	At this point, in Pittsburgh, most of the deconstruction is privately done. It's not done through the city. Recently some policies have been changed; before buildings are demoed, there is a list of evaluators for deconstruction, but it hasn't affected much on price so far.
Design complexity (DC) & Building story (BS)	The effectiveness of design complexity is high. If it's a one-story building with a flat roof or a simple roof with few gables, then it's easier to bring it down and cost less time and money. Building Story is part of design complexity.

b) AHP matrix & weights

AHP matrix is done with the numbers Terry gave to me.

Table 5.5: AHP Matrix according to Terry Wiles

AHP matrix from the interview (1 = least important and 9 = most important).

	BA	BC	AR	BS	BM	HM	GL	RP	DC
Building age(BA)	1	1/5	1/3	1/7	1/4	1/9	1/6	1/2	1/8
Building conditions(BC)	5	1	3	1/7	2	1/9	1/6	2	1/8
Building area(AR)	3	1/3	1	1/6	1/4	1/9	1/7	2	1/8
Building story(BS)	7	7	6	1	4	1/9	1	6	1/2
Building materials(BM)	4	1/2	4	1/4	1	1/9	1/8	1/2	1/7
Hazardous materials(HM)	9	9	9	9	9	1	2	8	1/2
Geographical location(GL)	6	6	7	1	8	1/2	1	5	1/3
Regional policy(RP)	2	1/2	1/2	1/6	2	1/8	1/5	1	1/8
Design complexity	8	8	8	2	7	2	3	8	1



Rank the 9 criteria from most to least weighted. According to Terry, Hazardous Materials (HM) & Design Complexity (DC) affect price most; the effectiveness of Building Age (BA) is least.

Table 5.6: Ranking of the Nine Criterion Weights according to Terry Wiles

Criterion	Weights
Hazardous materials(HM)	0.2813
Design complexity(DC)	0.2694
Geographical location(GL)	0.1467
Building story(BS)	0.1357
Building conditions(BC)	0.0489
Building materials(BM)	0.0401
Regional policy(RP)	0.0302
Building area(AR)	0.0300
Building age(BA)	0.0178

The following bar chart intuitively shows the weights of each criterion sequentially.

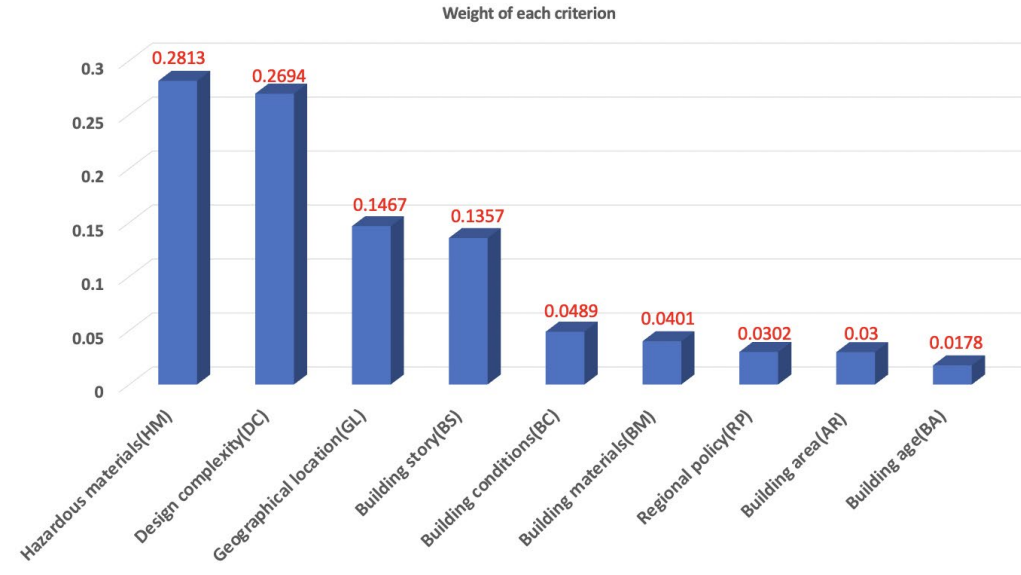


Figure 5.2: Weight of Each Criterion According to Terry Wiles

Combining the results calculated from information given by the 2 experts, the following bar chart lists the average weights of each criterion sequentially.

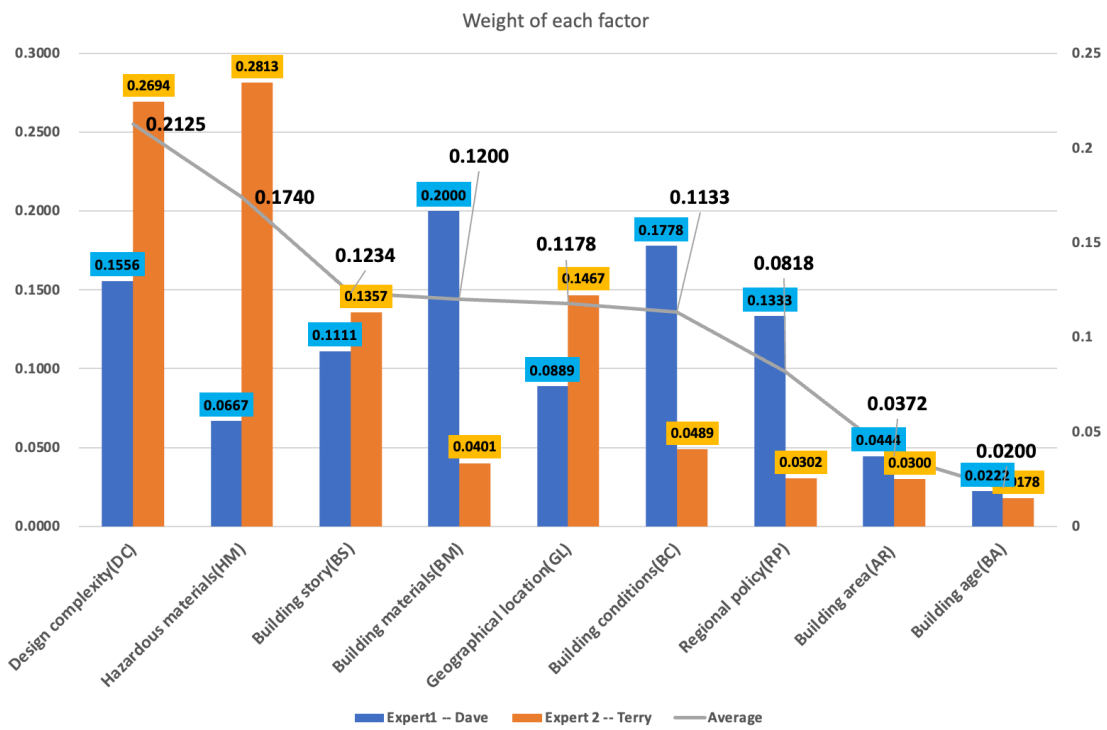


Figure 5.3: Weights of Each Factor by Interviewees

As viewed in the doughnut chart, materials, and design complexity (building story) were deemed to affect the cost of deconstruction most. Conversely, building age had the least influence on price.

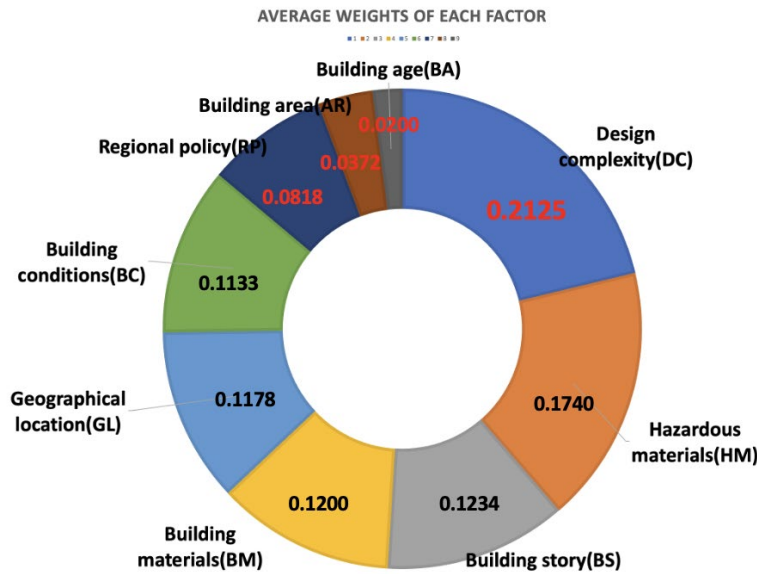


Figure 5.4: Average Weights of Each Factor Averaged

The above result can help decision-makers consider how to apply the weighting of these influencing factors to real deconstruction cases. To show the specific impact of the weight of these factors on the cost of the deconstruction project, based on some data from the case study (Tatiya et al. 2018), I used the Controlled Variable method for comparison.

Below I have listed four groups of data. Building A is the control case, whose variables are unchanged, leading to a deconstruction cost of \$20,000. Building B is the experimental case. For B, each group only changes the data of one variable and keeps the other variables the same as Building A's. The change of this variable data will cause a corresponding change in the deconstruction cost of Case B based on \$20,000. The percentage on the right shows the proportion of cost change. For example, Building Materials can positively impact a project's cost; more materials of value are present that exert downward pressure on the cost. So, the deconstruction cost of B will increase by 20% relative to A.

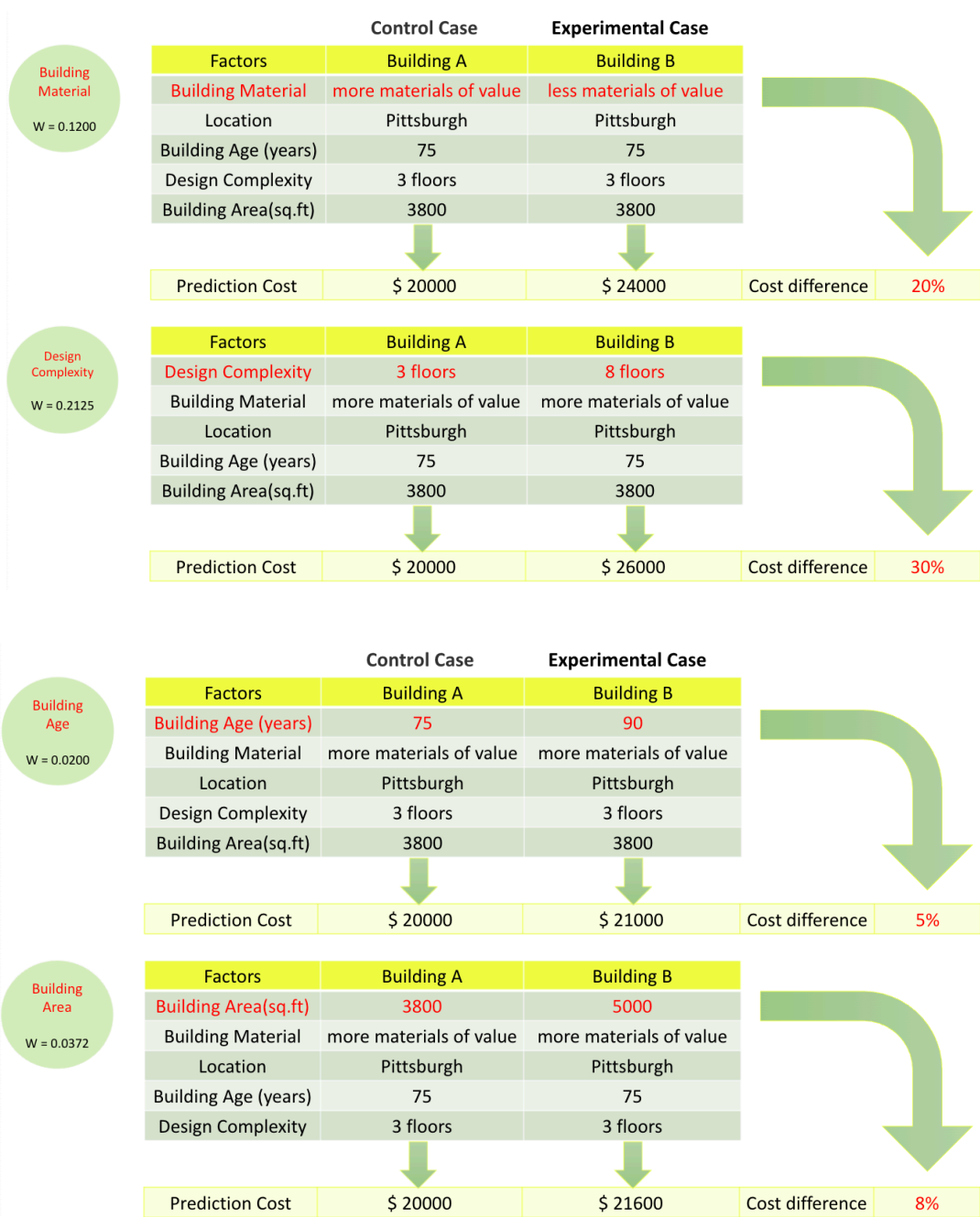


Figure 5.5: Control Variable Method for Building Materials, Design Complexity, Building Age, and Building Area

Analyzing these four groups of data, the percentage of the price difference between the control and experimental cases is positively correlated with the weight of the changing variable. According to our previous findings, the Building Complex has the highest weight, so the group with Building Complex factor changing leads to the most significant price increase - 30%. The previous calculation shows the weights of Building

Age and Building Area are the smallest, so their changes contribute to the small percentage of change in the deconstruction cost of Building B.

DISCUSSION, LIMITATIONS, AND FUTURE WORK

The findings above illustrate how Analytic Hierarchical Process based on the weight factors provided by deconstruction experts might help predict deconstruction pricing. This method could provide more accurate estimates to help decision makers make informed decisions about which properties should be prioritized for deconstruction. However, this is a preliminary study with two important limitations.

- 1) The data is limited due to the participation of only two experts. This process could be improved with a much larger set of local stakeholders (architects, demolition and deconstruction contractors, and waste management professionals) to provide a collective prediction of the impact in Pittsburgh.
- 2) The previous research and analysis showed that when one or several factors that affect the cost of the deconstruction project are changed, the proportion of the price change is positively correlated with the weight of the changed factor. Therefore, these calculated weights can be input to deconstruction prediction model and used as the coefficient for calculation better.

Therefore, future research should solicit input from additional experts and look into how to better apply these weights for cost prediction or calculation.

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CHAPTER 6 - LASER SCANNING AND BIM TO ESTIMATE DECONSTRUCTION RECOVERY POTENTIAL

WESTON FORTNA

ABSTRACT

The city of Pittsburgh recently began promotion of a deconstruction pilot program that may eventually impact more than 1,700 condemned buildings in order to eliminate blight and promote community development in a manner that is sustainable and economically viable. The program is currently in the early stages and working to identify potential techniques that can aid in streamlining the program. The use of 3-D scanning and Building Information Modeling (BIM) technology is becoming increasingly popular in the Architecture, Engineering, and Construction (AEC) industry and aids in creating 3-D visual models of buildings that can provide key building information such as material type and quantity. However, the current use of this technology is primarily applied to early stages of the project lifecycle and lacking in the deconstruction and demolition phases. This report sought to evaluate what aspects of 3-D scanning technology could be joined with BIM tools for application to the deconstruction and demolition phases of condemned buildings within the city of Pittsburgh. This was accomplished through extraction of methods through case studies and application of these methods via 3-D laser scanning and model creation of a building site in the vicinity of Pittsburgh. The site was a historic abandoned building in McKeesport, PA which was scanned throughout the interior and exterior utilizing two FARO 3-D laser scanners. The resulting scans were uploaded to Autodesk BIM software and served as a reference to create a 3-D visual model, which enabled generation of a material quantity takeoff sheet. This sheet indicated that approximately 606 tons of brick, 976 tons of concrete, and 139 tons of steel were present in the building which could be evaluated for potential salvage and recycling. Based on these results, it is recommended to City of Pittsburgh officials that a trial use of cost-effective 3-D scanning and BIM technology to deconstruction evaluations for condemned residential buildings. Furthermore, these methods could supplement current evaluation practices and be optimized to align with city goals and improve on-site safety while saving on costs and time in the deconstruction evaluation process.

INTRODUCTION

Throughout the world, waste generation generally correlates to global population growth, urbanization, and development, all of which are projected to continue growing over the next few decades (Kaza, et. al 2018, 17). Composition of waste varies by region and is also affected by factors that include local population size and regional wealth. Construction and demolition (C&D) waste is generated at approximately 1.68 kilograms per capita per day on a global scale (Kaza, et. al 2018, 36) and is estimated to contribute 50 percent of solid waste worldwide (Ge, et. al 2017, 1). Like the global trend for general waste, this category has been following an upward trend in recent years and is projected to continue growing with further global development (EPA 2015, 16). Within C&D waste, concrete and asphalt concrete comprise approximately 70 percent and 15 percent of accumulated debris, respectively, and demolition accounts for 90 percent of total debris generation (19). This highlights the need for deconstruction techniques to be enacted in the Architecture, Engineering, and Construction (AEC) industry, which can limit the amount of C&D debris entering the waste stream and aid in slowing global trends in overall waste generation through reduction, reuse, and recycling of building materials and maximizing material life span. Cities such as Baltimore, Portland, and Seattle have executed initiatives to combat the effects of C&D waste generation through reuse and recycling systems (Hines 2018), while cities such as Pittsburgh are implementing similar tactics through a deconstruction pilot program (City of Pittsburgh 2021). While these programs aid in improved management and reduction of C&D waste, their methods can be costly and time-consuming. Such projects could benefit from automation as a tool for site evaluation to increase their efficiency. Automated methods that may aid organizations in achieving this higher impact are Building Information Modeling (BIM) and associated technologies to include creation of multi-dimensional models through point cloud mapping and 3-D laser scanning in conjunction with thermographic imaging.

LITERATURE REVIEW

BIM is a relatively new technology that is becoming increasingly popular in the AEC industry. Specifically, this technology is praised for its vast capabilities that improve team communication and visualization for construction of a project, life cycle and facility management, and workflow optimization through 3-D modeling, construction simulations, and ease of access to project information by virtual means (Van Den Berg, et. al 2021, 1). While this praise is noteworthy and helps BIM gain momentum throughout the global AEC network, there is an apparent lack of BIM application in one key project life cycle process: demolition, deconstruction, and waste management (Ge, et. al 2017, 1). Numerous studies have researched potential uses of BIM in the deconstruction and demolition domains, with employed techniques that include converting facility drawings to a 3-D model, integration of deconstruction and demolition schedules to create 4-D simulations (Van den Berg 2021, 10), drone data collection with 3-D point cloud mapping and imaging (Ge and Wong 2017, 75), streamlining material quantification through 3-D models in lieu of on-site surveys, and developing waste management plans and cost benefit analyses (Hamidi, et. al 2014, 279). Not only do these techniques contain potential benefits for deconstruction and demolition projects, but they also promote the aforementioned advantages of automation by facilitating team coordination and communication, visualization of deconstruction and waste management plans, and workflow optimization among project stakeholders.

BIM integration in the pre-construction phases of a project is also linked to better waste management practices, as construction debris can be eliminated through error validation, and aid in design plans for the project's end of life phase (Won, et. al 2016, 172). Collectively, the literature indicates that advances and research in BIM as noted in the results can be a useful tool for deconstruction and demolition at a project's end-of-

life, however there are still challenges that must be overcome to achieve this. BIM practitioners and AEC professionals worldwide can aid in overcoming these challenges by further engaging in new technology practices in cost efficient manners. Furthermore, coordination among professionals on local, national, and global scale will aid in advancing these solutions throughout the industry to achieve a collective goal of improving waste management decision making in a safe and convenient fashion.

While the potential uses of BIM to aid in waste management seem promising, practical integration in the AEC industry will reveal successes and challenges with these strategies. Several case studies have been carried out to demonstrate the effectiveness of these methods, in varying locations that ranged from South Korea and the Netherlands to Australia. One evaluation of a wooden structure building utilized BIM 3-D modeling to determine material quantities and debris volume to conduct a faster cost-benefit analysis and waste management plan than traditional methods (Hamidi, et. al 2014, 285) while other projects utilized drone thermographic scanning and 3-D point cloud mapping methods in buildings to save an estimated \$1.1 million in landfill levy (Ge and Wong 2017, 76). Moreover, a case study on a residential building and sports complex utilized BIM in early project stages to eliminate construction errors and save a collective \$24,974 and 15.2% in overall construction waste (Won, et. al 2016, 180). These case studies serve as testaments to the advantages of employing BIM and associated technology in the case of deconstruction sites, but highlight that these practices are not commonplace throughout the industry on a global level. This suggests that there is high potential for social and financial cost savings through material reuse and waste management planning in the AEC industry with implementation of automated techniques on a wider scale.

While there were several successes indicative of BIM capabilities outlined in the case studies, several challenges remain before wide scale adoption to cities such as Pittsburgh can occur. First, BIM can be more expensive on initial investment due to the amount of hardware, software, and training associated with its use. This may deter professionals in the industry to transition from traditional methods and hinder progression for BIM deconstruction potential (Hamidi, et. al 2014, 286). Second, BIM use is fragmented throughout the AEC industry which proposes a challenge among professionals who will be limited in collaboration efforts due to lack of universal software, hardware, or methodology (Criminale and Langar 2017, 332). Third, developing technology for BIM such as 3-D point cloud mapping and drone integration further echo these challenges to a higher magnitude, making it difficult for professionals to acquire expensive mapping and drone technology that are not universal among professionals and require additional time and coordination (332).

PROBLEM STATEMENT & RESEARCH QUESTIONS

Based on the above information, it is clear that C&D waste composes a significant portion of the global waste stream that is projected to continually grow with a worldwide increase in population growth, urbanization, and societal development. This trend will contribute to adverse effects that include environmental degradation, climate change exacerbation, and increase in health risks and conditions to communities. Concrete and asphalt make up large portions of C&D waste debris which can be further reduced through effective deconstruction planning and tools, such as use of BIM and associated 3-D analysis technology. This includes multi-dimensional modeling of existing structures in the built environment with BIM software, which allows for extraction of material functionality and characteristics for waste and deconstruction planning and management. While use of this technology is growing in the AEC industry, its application for demolition and deconstruction is still lacking in global, national, and local contexts to be effective in waste management and deconstruction practices.

Research Questions

This study seeks to answer the following questions through research on BIM use and its application to waste management and the deconstruction industry:

1. How can BIM technology be utilized for demolition, deconstruction, and waste management in the AEC industry?
2. What capabilities of BIM can be implemented to create deconstruction and waste management plans for condemned properties within the city of Pittsburgh?

METHODOLOGY

To answer the proposed research questions in support of the problem statement, several methods were employed to gain insight into the applicability of BIM use and the associated gaps in waste management and deconstruction. The first method was the use of case studies, with a particular focus on global projects. Many European countries such as Denmark, Sweden, and Norway have mandated BIM integration for new construction projects and enforce these mandates on regional and local levels (BIMObject 2021, 5). Cases from these regions enabled study of global projects where resulting BIM techniques were extracted for potential application in the United States and Pittsburgh, namely multi-dimensional modeling, 3-D point cloud mapping, and thermographic imaging. Moreover, the case studies provided further insight to potential challenges and developments of BIM within deconstruction and waste management avenues that lead to further exploration into remedies for these challenges.

The next set of methods utilized involved application of extracted information from relevant case studies to a local building site in the vicinity of Pittsburgh, PA. Through the Civil and Environmental Engineering Department at Carnegie Mellon University and a local nonprofit organization, the Regional Industrial Development Corporation (RIDC), a collaborative site visit was conducted to a local abandoned historic building for deconstruction evaluation. The building was the RIDC-owned McKeesport Roundhouse, located in McKeesport, PA on the south shore of the Monongahela River. Constructed in 1903 for service as a connecting station for the McKeesport railroad (Togyer 2013), the building was utilized for more than 120 years, until recently in 2013 when the railroad was merged with the Union Railroad and the connecting station was no longer needed (Togyer 2013). The main building area of the roundhouse is approximately 20,000 square feet and is two stories high, as seen in Figures 6.1 and 6.2 below.

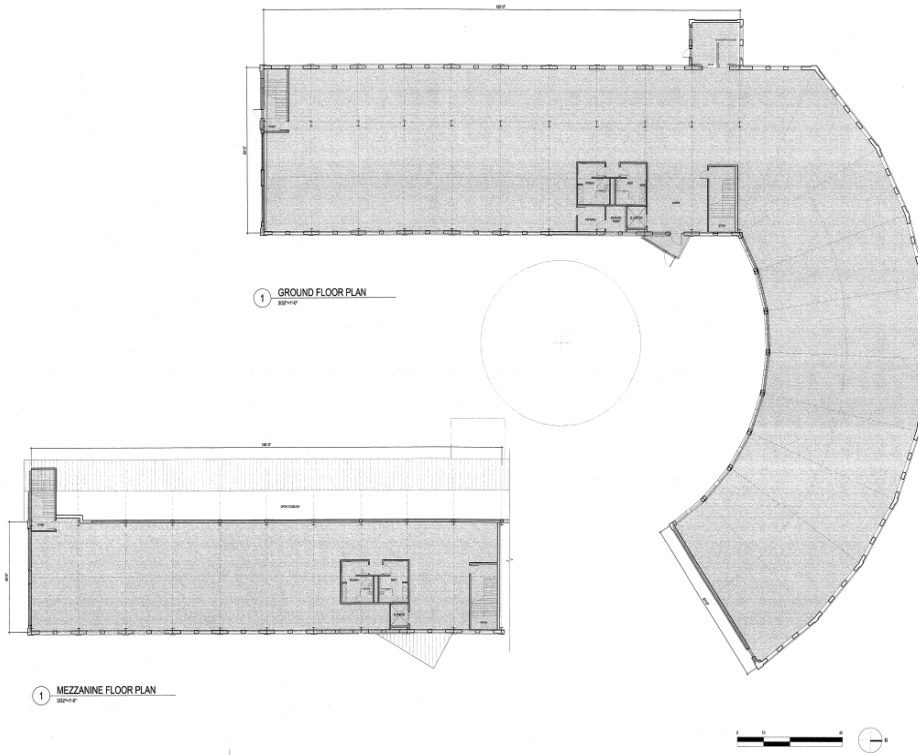


Figure 6.1: Ground Floor Plan for McKeesport Roundhouse (RIDC)

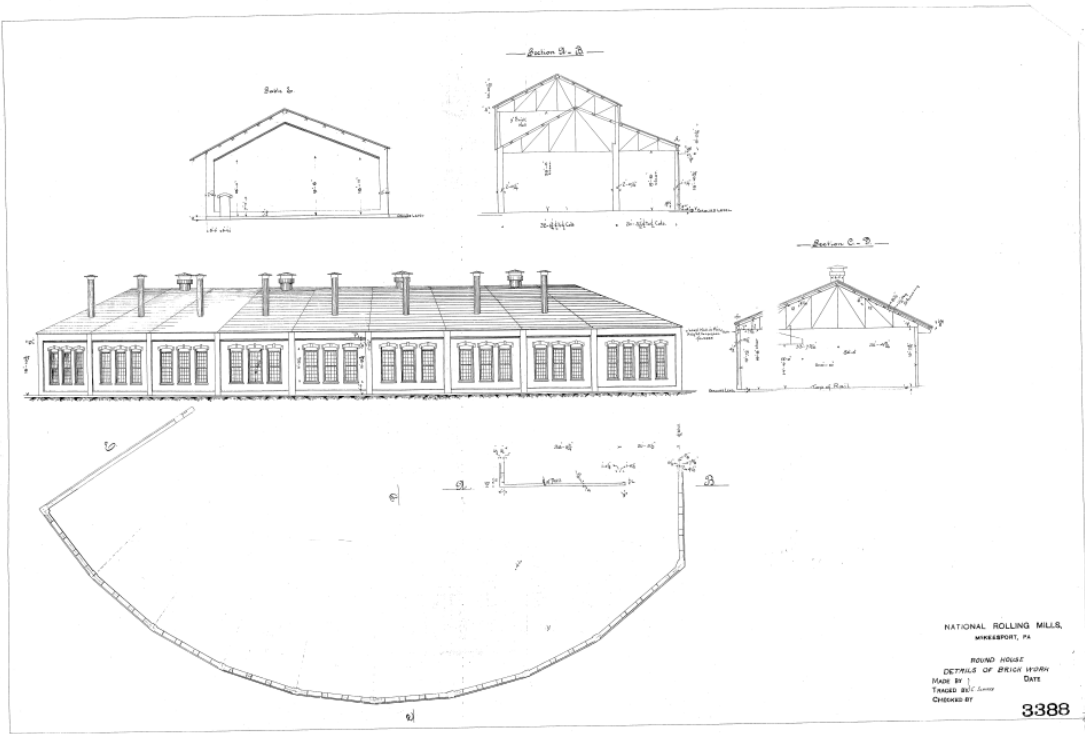


Figure 6.2: Elevation and Section of McKeesport Roundhouse (RIDC)

Utilizing two FARO 3-D laser scanners provided by the Carnegie Mellon University Civil and Environmental Engineering Department, along with collaborative efforts from associate professor Dr. Pingo Tang and doctoral degree candidates Pengkun Liu and Ruoxin Xiong, laser scans of the interior and exterior of the building were captured in addition to several images for assessment of the building material types. The laser scanning consisted of 34 laser scan point cloud captures comprised of the entire exterior and interior of the building from ground level. The scans were uploaded and registered to a consistent relative coordinate grid system using Autodesk ReCap Pro, resulting in comprehensive 3-D models of point cloud data, as seen below in Figures 6.3 and 6.4.

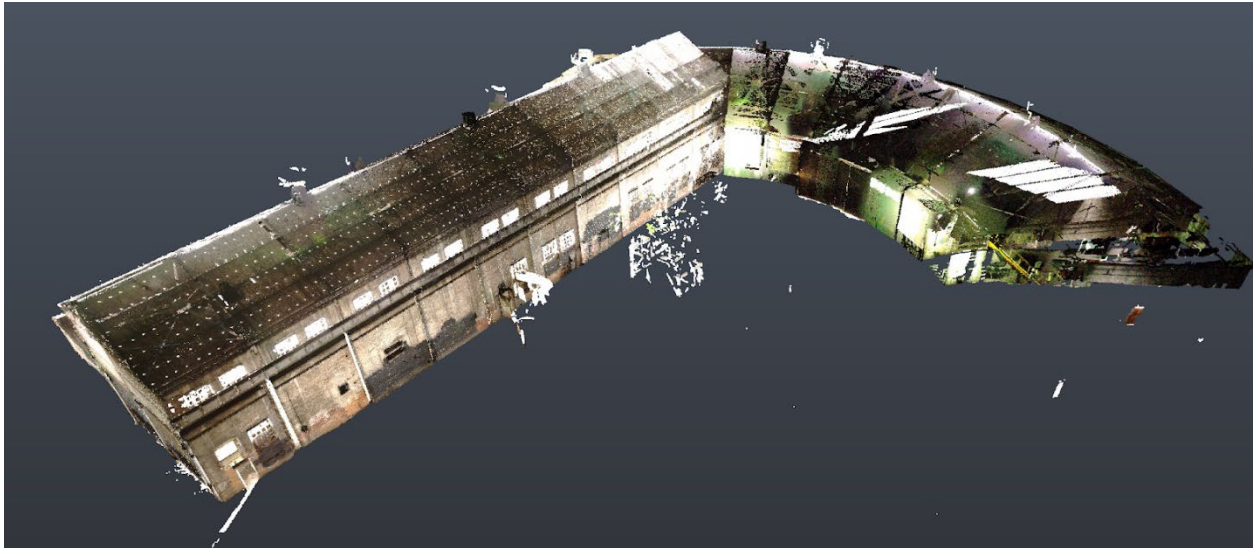


Figure 6.3: Interior Point Cloud Data Model of McKeesport Roundhouse

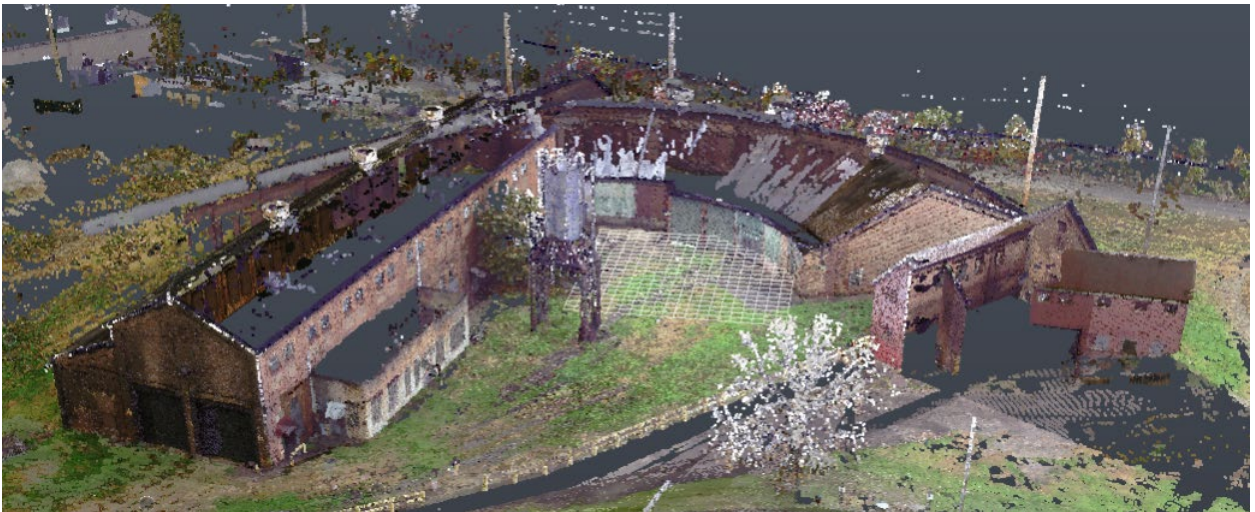


Figure 6.4: Exterior Point Cloud Data Model of McKeesport Roundhouse

The model was transferred from Autodesk ReCap Pro to Autodesk Revit, where it was cross referenced with the 2-D drawings and photos captured during the site visit. This formed the basis for creation of a 3-D model; these elements served as an outline in which 3-D components could be added and manipulated to precisely reflect the on-site conditions and materials. The resulting 3-D model is illustrated in Figure 6.5 and Figure 6.6 below.

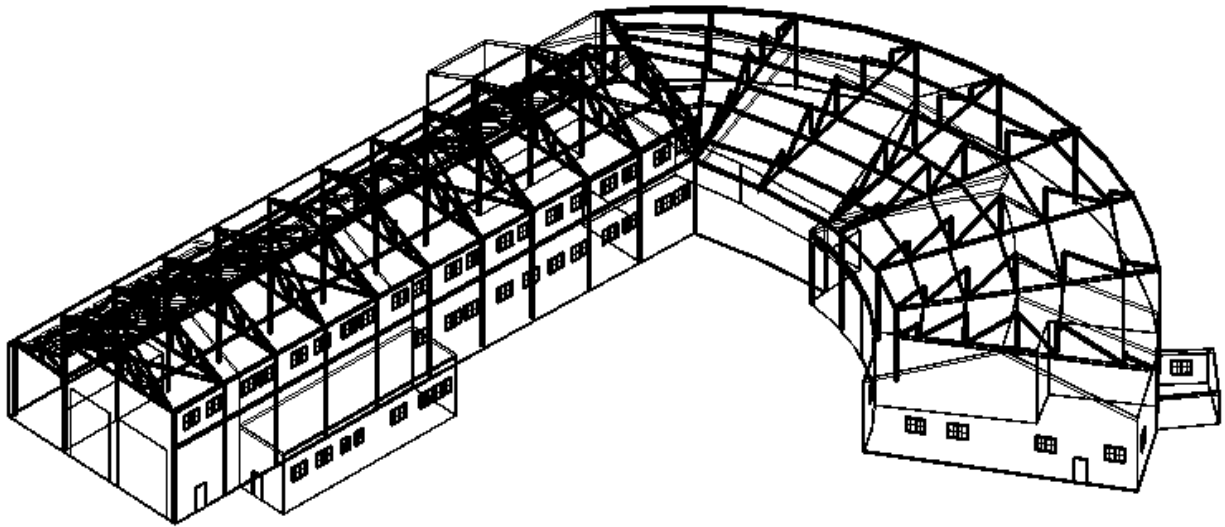


Figure 6.5: Interior 3-D Building Information Model of McKeesport Roundhouse

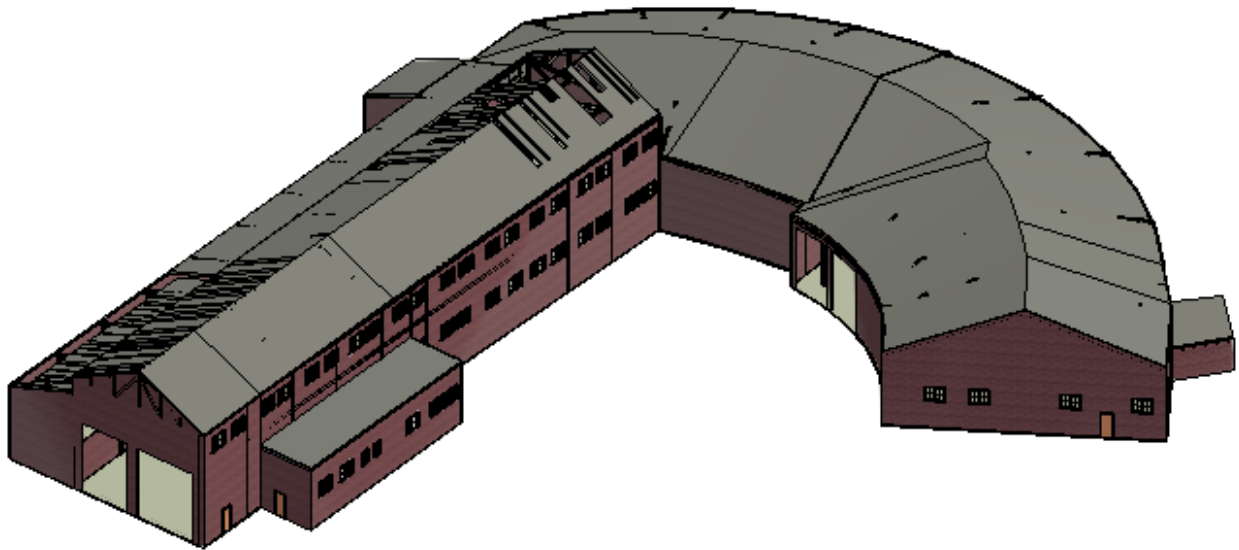


Figure 6.6: Exterior 3-D Building Information Model of McKeesport Roundhouse

Once complete, Autodesk Revit was used to generate a material quantity takeoff sheet for the building, resulting in an encompassing list of each material, its volume, area, and quantity throughout the model. A sample of a material quantity takeoff sheet is displayed in [Figure 6.7](#) below.

<Sample Material Quantity Takeoff - Brick>			
A	B	C	D
Family and Type	Material: Name	Material: Volume	Material: Unit weight
Basic Wall: Generic	Brick, Common	1185.21 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	99.52 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	487.31 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	232.52 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	328.51 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	100.46 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	933.22 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	662.88 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	184.25 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	50.35 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	72.07 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	29.04 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	302.80 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	40.36 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	341.65 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	140.88 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	101.54 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	1620.89 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	104.31 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	140.65 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	164.75 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	628.33 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	94.46 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	267.88 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	51.62 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	165.59 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	310.24 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	92.34 CF	121.73 lb/ft ³
Basic Wall: Generic	Brick, Common	206.81 CF	121.73 lb/ft ³

Figure 6.7: Material Quantity Takeoff Sheet for McKeesport Roundhouse Model

RESULTS AND DISCUSSION

The material quantification takeoff sheet was able to be sorted by material type where resulting volumes were subsequently compiled. This analysis revealed that the building contained 606 tons of brick, 976 tons of concrete, and 139 tons steel. Utilizing

the University of Bath International Carbon and Energy Database, the amount of embodied carbon contained in these materials was extracted and applied to these volumes, based on a mass ration. The extracted values were selected based on the assumption that the respective materials were comprised of generic material composition. For example, the embodied carbon value extracted for concrete was that of generic concrete composed of 80 percent Portland Cement and 20 percent of other aggregates. This yielded respective embodied carbon estimates of 127 tons of Carbon Dioxide Equivalent (CO₂e) for brick, 101 tons of CO₂e for concrete, and 216 tons of CO₂e for steel. These are preliminary estimates of material quantity and embodied carbon of the studied building which could aid in developing a building deconstruction and waste management plan for reusing, recycling, and discarding materials. Furthermore, these valuations could aid in making future design decisions with regards to sustainability and provide perspective on the environmental impact of buildings and composed materials, while also providing insight to decision makers and stakeholders involved in the deconstruction process.

While these results could be obtained through conventional deconstruction evaluation methods, the laser scanning and automated BIM process holds several advantages that could streamline a building's deconstruction evaluation. First, the amount of time invested in the evaluation of a building can be significantly reduced through the BIM evaluation process; the 3-D laser scans utilized in this report required approximately eight minutes per scan and can significantly reduce the amount of time measuring and documenting dimensions that would be completed through the conventional method with a tape measure or other manual metering device. The creation of the 3-D model using BIM software required about 20 to 25 hours from a beginner-level, which could easily be improved through experienced BIM experts or freelance contractors with BIM software certification. Secondly, the quality and condition of materials can be more accurately and easily captured using the BIM method in comparison to the conventional method. An example of this includes missing roofing in the McKeesport Roundhouse which could easily be captured and emulated via laser scan and BIM software and would otherwise not be easily evaluated using conventional 2-D drawing and manual measuring techniques. This example also illustrates an element of increased on site safety that may not be feasible through conventional evaluation methods; the laser scans in this report easily captured the dimensions of missing roofing on the site that would otherwise require a person to manually measure by climbing onto the building's roof. This risks instability and failure of the roofing, leading to potential injury as well as inability to accomplish a thorough on-site deconstruction evaluation.

While these results could be obtained through conventional deconstruction evaluation methods, the laser scanning and automated BIM process holds several advantages that could streamline a building's deconstruction evaluation.

This mentality could also be applied in other hazardous condition scenarios that could include loose wiring or plumbing systems or instable flooring that could easily be captured by 3-D laser scanning and would not require risk from manual technician methods. From a practical perspective, this methodology could also be applied to buildings with complex geometries or design aspects. For example, a condemned single family Victorian style home with missing schematic drawings, complex architecture, and unpermitted add-ons could be very labor intensive and difficult to visually replicate and estimate by conventional methods. Through use of automated technologies, this building could easily be captured and digitally represented through 3-D laser scans and BIM software. This would in turn enable a more thorough and robust analysis among project stakeholders and create potential for optimized workflow and coordination among decision makers.

The use of the BIM method can also further aid in providing visual simulation and evaluation that could not be easily accomplished by conventional means. 3-D modeling

enables accurate material labeling that could be used to easily identify portions of a building for reuse, recycling, or transport to a landfill and can be further specified through color-coding and material characteristic labelling, as illustrated in Figure 6.8 below.

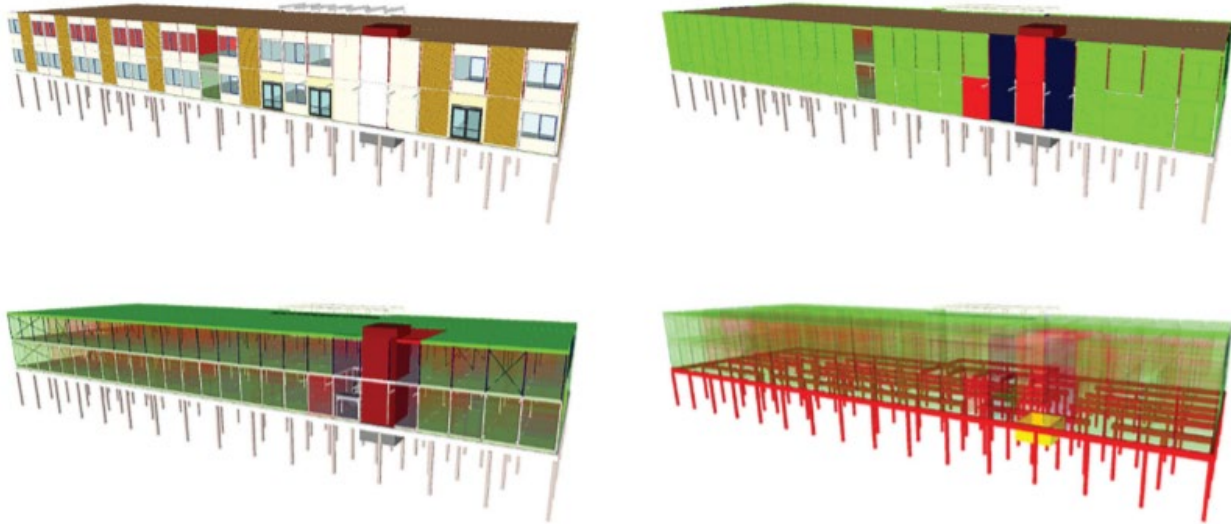


Figure 6.8: Example of Color Coding for Material Characteristic Labelling
(Van den Berg, et. al 2021, 333)

Moreover, BIM can be utilized to apply project scheduling timeframes to specific building portions and materials that can illustrate the proposed deconstruction methodology and timeline. This can also be further enhanced with cost assignments to various materials, enabling more comprehensive material value assessments that are automated and readily available. Ultimately, this process demonstrated how BIM analysis can be more advantageous in deconstruction and waste management evaluation when compared to traditional methods within the built environment. The use of BIM in this regard offers several potential benefits that could aid and improve deconstruction pilot programs and existing initiatives while also offering means to develop solutions that combat the growth of the C&D waste stream on local, regional, and global scales.

Limitations

The process of 3-D laser scanning on an existing historical building and creating a 3-D model through BIM software revealed various limitations that may present challenges when applied to condemned buildings or properties within the city of Pittsburgh. These limitations may be overcome with a hybrid model of conventional surveying and automated methods. Full automation of quantification of building materials is efficient, but still poses many challenges. First, the BIM software proposes expenses that may not be economically viable for local governments or small organizations. In the case of using Autodesk software, there are various subscription options as well as software packages that can be chosen, but the modeling software Revit has an annual subscription price of \$2,545 with a 3-year price of \$6,870 for one license (Autodesk). Moreover, this subscription is only available for single-user use, as perpetual and multi-user licenses are no longer available. Furthermore, Autodesk's point cloud software ReCap Pro has a similar pricing structure, with an annual subscription cost of \$340 and 3-year cost of \$920 (Autodesk). Despite this, there are other low cost and open-source software options that are BIM based and similar to that of Autodesk products,

however this can limit the compatibility between various programs and result in losses of data. For example, the free point cloud software Cloud Compare may not be completely compatible in translating point cloud files to the free modeling software FreeCAD when compared to Autodesk products (AlternativeTo 2021).

Another limitation in this regard are expenses associated with the procurement, operation, and maintenance of equipment utilized to perform 3-D scans. The FARO laser scanning equipment utilized in this study vary by capability, but can cost upwards of \$20,000 for one scanner (FARO 2021). Moreover, other equipment such as drones have varying costs based on capability and require training and certification for operation in commercial uses, which are subject to airspace limitations (FAA 2021). On the contrary, more affordable options with light detection and ranging (LiDAR) technology are becoming increasingly available to users. Recent iPhone and iPad models are equipped with LiDAR sensors and have access to various applications that can capture up to 9 million dimensionally accurate points with a single scan (AEC Magazine 2020).

Other limitations associated with this process include occlusions during the 3-D laser scanning process as well as misrepresentation of materials. Occlusions occur during the 3-D laser scanning process when an object or component is blocking the view of the laser scanner lens. This can also occur when conditions such as sunlight, shadow, inclement weather, workers, or equipment are present on the site when the scanning is taking place. Figure 6.9 below illustrates common examples of occlusion that can occur on an active work site.

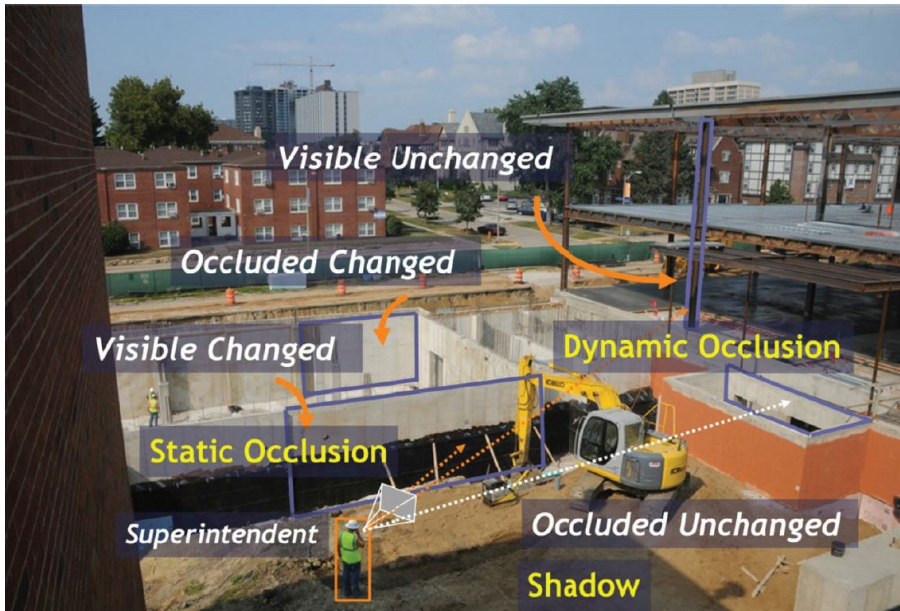


Figure 6.9: Example of Occlusions on Active Construction Site
(Xue, et. al 2021, 24)

This challenge was experienced when performing a laser scan of the outdoor portion of the McKeesport Roundhouse, where the east wall was in close proximity to another building on the property. This provided limited space for the laser scanner to operate, which in turn could result in loss of detail when importing the scans to computer software for analysis. This is highlighted in Figure 6.10 below.



Figure 6.10: East wall of McKeesport Roundhouse (left) and adjacent building (right)

Additionally, the condition of the building can provide a challenge in creating a 3-D model using BIM software which in turn would provide an inaccurate material quantification of the building. While hazardous conditions are easily and safely captured through image and laser scan collection, these elements may be difficult to fully replicate in BIM software for someone with beginner-level experience. Furthermore, hazardous or abnormal building conditions would also increase the amount of detail and time needed to be input into the 3-D model, which could be better optimized in development efforts.

Recommendations

Based on the results, interpretation, and limitations, it is recommended that cost effective options of automated material quantification analysis be explored and applied towards residential condemned properties within the city of Pittsburgh. This could be done utilizing open-source BIM software as well as the relatively inexpensive LiDAR technology and supplementing with current evaluation and quantification methods. This would ultimately provide insight and a low-cost trial that could be employed during the city of Pittsburgh deconstruction pilot program and scaled accordingly based on the results and usability. Furthermore, these techniques could be supplemented with current conventional practices to fulfill gaps or limitations by both methods and promote a hybrid process with robust results. This could progress to modification of methods that lead to further investment in relevant software as well as additional equipment such as 3-D laser scanners or drones, but also could provide a low-risk implementation trial that could potentially yield high benefits for the future of the program.

Future Research

Additional research and implementation could help to provide insight to the practicality of BIM in the deconstruction industry as well as the automated software and equipment utilized to do so. This could include the employment of LiDAR technology in recent iPhone and iPad equipment, use of drones or other thermographic imaging tools, and utilization of these methods on potential deconstruction projects to include residential and commercial properties. Additionally, the use of BIM as a means of design for deconstruction could be further researched and explored for integration in the AEC and deconstruction industries. The use of BIM in early stages boasts potential for eliminating rework or lifecycle disruption of buildings and could also provide insight and ease in the deconstruction and reuse of a building in future applications. Moreover, existing multi-dimensional models could easily be accessed in the deconstruction process of a building, which would eliminate or vastly reduce the need for laser scanning and multi-dimensional model creation for buildings, thereby saving labor, time, and costs associated with this process.

Additional resources in BIM mapping and modeling software and scanning technology can also be explored in the Building Reuse spaces, as development and research progresses in the coming years. Examples of this could include use of the tools employed by the Buildings As Material Banks (BAMB) throughout Europe or the Circular Construction Lab in Ithaca, New York which are creating innovative and user-friendly scanning software that integrate laser scanners and LiDAR sensors for building material evaluation. Additionally, further dimensional development of 3-D visual models could aid in automating the deconstruction process to include project scheduling and cost analysis that would form a single source comprehensive model that could easily be evaluated by relevant stakeholders for a project.

Collectively, these tools could further enhance a building's deconstruction and waste evaluation process as well as provide economic and social value for communities within the AEC industry. The integration of automated methodology to existing conventional methods of building evaluations promote a safer, sustainable, more thorough, and cost-efficient process in the long term, which can be further improved and expanded upon to optimize workflow and maximize material life in the built environment. This would ultimately aid in the reduction of C&D waste and enable an environmentally conscience framework for the AEC industry in support of worldwide social and economic benefits for the future.

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