Flow of waste and a method for prediction of demolition waste generation from buildings – A case study in Hanoi, Vietnam

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Abstract. Being the capital of Vietnam, a dynamic developing country, Hanoi is experiencing a rapid rate of urbanization and economic growth which leads to the continuing increase of construction and demolition activities. In the recent few decades, construction and demolition waste has been accounted for a large amount of solid waste in urban areas, among which demolition waste (DW) is the major content. This study aims to sketch the flow of DW post-demolition, as well as to provide an approach to predict the estimated DW generation in the future in Hanoi. Data of DW generation rate from previous study in Hanoi is combined with statistics of construction in the city to work out a reasonable model of projection of DW for further recommendations for managing this type of waste for sustainable development.

1. Introduction
With the boom in economy, the construction industry in Vietnam has been rapidly growing to meet the demand of better and more sufficient infrastructure or accommodation. As a result, construction and demolition waste (CDW) created from these activities has become one of the biggest concerns for the environment. A recent study reveals that the amount of CDW “accounts for 10-12% of total municipal solid waste generated, equalling about 9,000 tonnes/day in Vietnam” [1]. Such a massive amount of solid waste exerting pressure on the incomplete and unprofessional system of environment management is becoming a contemporary issue realized and addressed by Vietnamese government. Hanoi is the second-largest city of Vietnam (the largest one being Ho Chi Minh City), and is a particularly vibrant city especially in the field of construction. According to a survey in 2009 conducted by Vietnam Association of Urban Environment and Industrial Zone, it was reported that approximately 1,000 to 1,500 tons of CDW was generated in Hanoi per day [2]. Since the moment of that survey, it is reasonable to state that these numbers have increased rather significantly following the development rate of the city. For many years, the main method for getting rid of CDW in Hanoi is to dump illegally at unprotected areas, lakes, water streams, etc. [3]. There is not yet an effective system of collection and treatment of CDW in Hanoi, and this will surely put heavy pressure on the urban environment in the near future. It is important to distinguish between construction waste (CW) and demolition waste (DW) which make up the content of CDW. While CW is generally understood as materials discarded from the construction of new structures, DW is generated from the renovation or demolition of built structures. This paper focuses on the latter category, and since it makes up the majority of CDW, studies on DW flow and generation from buildings play a crucial role in the effort to mitigate and manage such category of solid waste in Hanoi.
A number of studies have been conducted on CDW in Vietnam, some of which selected Hanoi as case study. For instance, Lockrey et al. [4] predicted that the total amount of CDW in Vietnam in 2020 and 2025 were around 6.3 million tons and 11 million tons, respectively, and also provided further insights into the CDW management situation in Vietnam as well as in Hanoi. In this study, a combination of literature review, interview and site investigation were applied to summarize practices in handling CDW, and then projected by analysing both material flows and recycling rates. By synthesizing existing knowledge, Nguyen et al. [3] presented a thorough sketch of overall situation, practices and legislation, together with challenges and opportunities in recycling CDW in Vietnam. Recommendations were also proposed for the proper management of this enormous amount of solid waste which was claimed to cause “risks to human health and environment”. In an attempt to reliably quantify CDW generation in Hanoi, Ishigaki et al. [1] adopted the method of site survey and image analysis to work out waste composition. The authors were able to determine the generation rate of CDW by category such as construction (small scale and large scale), demolition (small scale and large scale), and public works. An independent study by Nghiern et al. [4] in the same year gave a similar estimation of waste generation per unit floor area from demolition work in Hanoi employing a different approach. Within the same publication, the authors conducted interviews with various construction and demolition contractors in Hanoi and Ho Chi Minh City in order to assess their scale and business, their awareness of current legislation of CDW management, together with their attitude towards the prospect of recycling CDW. Lockrey et al. [5] used information gathered from interviews to develop a life cycle assessment (LCA) model in order to simulate CDW flows in Hanoi, especially focus on the potential of adopting recycle products from CDW for concrete mixing. The paper concluded on the economic attractiveness of such model, and its benefits in solving environmental issues in Vietnam.

The objectives of this study include: summarize a complete flow of DW in Hanoi, Vietnam as of current practices; and propose a method to predict and project the amount of DW generated from building construction activities in the city. Both objectives aim towards providing a more thorough understanding of current DW management situation in Hanoi, thus giving appropriate recommendations of further studies, as well as policies to minimize its impacts on sustainable development goals.

2. Methodology

To achieve the first objective, a combination of two methods of collecting data: interview and site visit were adopted. The authors were able to identify a key collaborator in Hanoi – one of the important demolition contractors who frequently take on large demolition projects in the city, as well as in adjacent provinces. During the period of investigation, the key collaborator not only provided detailed information on the current practices in handling DW, but also allowed access to various demolition sites. Furthermore, initial introduction from a reputable demolition contractor enabled the authors to approach several other similar contractors to verify such practices. Due to the complicated nature of CDW management situation in Hanoi in general, in order to conduct such interviews successfully, the identity of collaborators was promised to be kept confidential. Information gathered were summarized into a general diagram of DW flow in Hanoi.

On the other hand, to predict the DW generation from buildings in Hanoi in the future, the authors propose combining the data of construction in the city through referring to Hanoi Statistical Yearbook [6], and DW generation rates published in previous studies. The “Investment and Construction” is an essential part included in every statistical yearbook, in which it is possible to find out the total floor area constructed in the most recent years. The data is also categorized by type of buildings into: apartment (sub-categories: by number of floors), and private house (sub-categories: by number of floors, and villa). For the sake of simplicity, two types of building structures are considered in this study: low-rise buildings (less than 4 floors) and buildings (5-26 floors). The total floor area constructed of these two types of building structures are denoted as $A_{\text{low-rise}}$ and $A_{\text{buildings}}$. 
For the determination of DW generation rate to be employed in this paper, two related publications were selected for comparison of results as shown in Table 1. It is clearly observed that the two studies share a number of concepts when quantifying generation rate. Ishigaki et al. considered a wide variety of DW in the analysis, among which the main contents were concrete, brick, and mortar. These materials fit the description of crushed concrete and crushed brick by Nghiem et al. Moreover, both papers listed metal as one of the important compositions of DW. In this study, as the target of concern is DW in general, it is proposed that the above materials’ generation rates are summed to calculate the value of DW generation rate.

For the category of low-rise buildings, Ishigaki et al. did not include them within the survey. Hence, the value of DW generation rate of private house is adopted from Nghiem et al. as follows:

$$G_{\text{low-rise}}^{\text{DW}} = 1.39 \ \text{tons/m}^2$$  \hspace{1cm} (1)

Table 1. Comparison of DW generation rate from demolition work in Hanoi, Vietnam in existing literature.

| Items of comparison | Ishigaki et al. (2019) | Nghiem et al. (2019) |
|---------------------|------------------------|----------------------|
| Category of work    | Demolition             | Demolition           |
|                     | N.A.                   | House owned by individuals |
|                     |                        | (Number of floors less than 4) |
| Sub-category and types of structures surveyed | Small scale | Office, apartment, and school |
|                     | Office, apartment, house, and school | (Floor area less than 10,000 m$^2$) |
|                     | Large scale            |                        |
|                     | Apartment, factory, house | N.A. |
|                     | (Floor area more than 10,000 m$^2$) | |
| Category of DW considered | Concrete, brick, mortar | Crushed concrete – crushed brick |
|                     | Metal                  | Metal (steel and aluminium) |
|                     | Other DW               | N.A. |

For the category of buildings (5-26 floors), it is reasonable to employ the results of building structures with floor area less than 10,000 m$^2$. In this category, Ishigaki et al. worked out the generation rate of $$G_{\text{buildings}}^{\text{DW1}} = 0.506 \ [\text{tons/m}^2]$$, while Nghiem et al. came up with the value of $$G_{\text{buildings}}^{\text{DW2}} = 0.492 \ [\text{tons/m}^2]$$. Being independent studies and adopting different methods of quantification, the two results have good agreement. Therefore, it is possible to take the average DW generation rate to proceed with further calculations as follows:

$$G_{\text{buildings}}^{\text{DW}} = 0.499 \ [\text{tons/m}^2]$$  \hspace{1cm} (2)

Combined with the data of total floor area constructed per year, the amount of DW that new building construction within that year would generate when demolished can be estimated as:

$$DW_{\text{low-rise}} = A_{\text{low-rise}} \times G_{\text{low-rise}}^{\text{DW}}$$  \hspace{1cm} (3)

$$DW_{\text{buildings}} = A_{\text{buildings}} \times G_{\text{buildings}}^{\text{DW}}$$  \hspace{1cm} (4)

Adopting a linear model of extrapolation, the authors are then able to derive a rough prediction of DW generated in Hanoi in relation with the data of constructed floor area.
3. Results and Discussion

3.1. Typical DW flow in Hanoi

Nine buildings in Hanoi were observed and recorded throughout the demolition process. During such period, semi-structured interviews were also conducted with various stakeholders involved, including: owner (in the case of low-rise buildings), former inhabitant/employee of building (in the case of buildings of 5-26 floors), manager of the demolition contractor, worker, machine operator, and scrap buyers. Collected information revealed the practice of handling DW, and the destinations of various types of DW generated from building structures in Hanoi. The DW flow from building demolition sites can be sketched as shown in figure 1.

![Diagram showing DW flow from building demolition sites in Hanoi.](image)

**Figure 1.** DW flow from building demolition sites in Hanoi.

It is observed from the diagram that a minor part of DW is reused and recycled, including salvageable housewares and all metal materials. The bulk of DW, however, lies in the huge volume and mass of mixed waste that is generated from concrete, reinforced concrete structural components and brick walls. Through in-depth discussions with the key collaborator, it was found out that excessive mixed waste was supposed to be dumped at landfills specified by Hanoi People’s Committee. The number of such landfills, however, were limited; together with the fact that they were very quickly filled up rendered them ineffective in controlling the reality of illegal dumping.

3.2. Current situation of building construction in Hanoi from 2016 to 2018

Due to the development of the economy, as well as the need to demolish degraded old buildings, the construction and demolition rate in Hanoi city is rapidly increasing each year. From 2016 to 2018, the total number of floor area constructed in Hanoi has been growing at a rate of roughly 3.5-4% annually [6]. Figure 2 summarizes the rising trend of floor area constructed by type of building in the latest three years 2016, 2017, and 2018; while table 2 presents the raw data of the supplied statistics. It is observed that with such a stable rate of increment for the two types of building considered, it is possible to adopt a linear extrapolation to project the unannounced data of subsequent years.
Figure 2. Rising trend of floor area constructed by type of building in Hanoi.

Table 2. Statistics of floor area constructed in Hanoi in recent years by type of building and data projection of subsequent years.

| Type of building          | Floor area constructed annually by type of building (Thousand m²) | 2016 | 2017 | 2018 | 2019 (projection) | 2020 (projection) |
|---------------------------|------------------------------------------------------------------|------|------|------|-------------------|-------------------|
| Low-rise buildings        |                                                                  | 8,551| 9,216| 9,461| 9,986             | 10,441            |
| (A_{low-rise})            |                                                                  |      |      |      |                   |                   |
| Buildings (5-26 floors)   |                                                                  | 1,722| 1,703| 1,863| 1,903.5           | 1,974             |
| (A_{buildings})          |                                                                  |      |      |      |                   |                   |

3.3. Prediction of DW generation from recently constructed buildings in Hanoi in the future

Having collected the data of floor area constructed in Hanoi in recent years by type of building, as well as worked out the projection of such numbers, it is possible to employ equations (3) and (4) established in previous sections to calculate the amount of generated DW when all these buildings are demolished. It is worth restating that the categories of DW considered in this paper include: crushed concrete, crushed brick and mortar, tile, and metal (mainly steel and aluminium). The total amount of DW generation is estimated and projected as shown in table 3. Figure 3 presents the adopted linear extrapolation.

Table 3. Estimation and projection of DW generated when demolishing all buildings constructed in recent years in Hanoi.

| Type of building          | Prediction of DW generated by type of building (Thousand ton) | 2016 | 2017 | 2018 | 2019 (projection) | 2020 (projection) |
|---------------------------|----------------------------------------------------------------|------|------|------|-------------------|-------------------|
| Buildings (5-26 floors)   |                                                                  | 1,240| 1,226| 1,341| 1,371             | 1,421             |
| Low-rise buildings        |                                                                  | 11,886| 12,810| 13,151| 13,881         | 14,513            |
Figure 3. Predicted amount of DW generated from recently constructed buildings in Hanoi.

DW generated from both types of building considered in this study are experiencing constant trends of rising. While the average rate of increment in the category of low-rise buildings is 5.14%, that in the category of buildings (5-26 floors) is slightly slower at 4.09%. It is also observed that the majority of DW will actually come from demolishing small building structures of less than 4 floors. Not only does the total floor area constructed of this type of building is larger, it also generates much more DW. This can be explained by the fact that low-rise buildings (usually private houses) have short spans, thus intensifying the density of reinforced concrete members. Furthermore, they are often built with many brick walls serving as partition walls, unlike buildings of larger scale.

4. Conclusion
Through interviews and thorough investigations, the paper was able to summarize the typical waste flow of DW in Hanoi. It is clearly observed that apart from salvageable components of a building, only a small amount of DW is separated – profitable materials (namely metals such as steel or aluminium). The remaining mixed waste not only is not classified and can sometimes contain hazardous materials, the majority of it is also dumped illegally. Together with a rapid rate of urbanization, it is crucial that DW be managed properly to minimize the impact on urban environment in the near future. Compulsory sorting of DW, as well as the promotion of DW recycling can be the initial steps that Hanoi can follow in such an overall goal. By combining data of existing knowledge, a method for predicting the amount of DW generated in Hanoi in the future was also proposed. The projection agreed on the increasing rate of 4-5% per year of future DW, accumulated by constructing new buildings. It is advisable to explore the concept of circular economy in order to optimize the use of construction materials, thus controlling both the amount of CW and DW. Such recommendations may potentially be topics for future studies of CDW in Hanoi.

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