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CASE STUDY

Integrating urban building information modeling and circular economy framework for green sustainability

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ABSTRACT

BACKGROUND AND OBJECTIVES: The conventional disposal of demolition waste in landfills poses significant ecological harm. Integrating principles of the circular economy can help alleviate this impact by encouraging the reuse, recycling, and recovery of materials. This study presents a groundbreaking approach to demolition that aims to tackle the growing waste problem and bridge the existing regulatory loopholes. The framework leverages Building Information Modeling for Just-In-Time delivery and circular economy practices to prioritize environmentally friendly, efficient, and sustainable operations. The framework aims to transform demolition practices, reduce environmental impact, and promote sustainability within the construction sector by incorporating these principles.
METHODS: The study outlines a plan for demolishing high-rise buildings by incorporating Building Information Modeling, Just-In-Time delivery, and the circular economy in a specific case analysis. Autodesk Revit streamlines waste estimation and inventory of reusable, repairable, refurbished, and recyclable waste, thereby optimizing waste management planning with improved effectiveness and efficiency. Navisworks visualizes the demolition process in a reverse four-dimensional model. Microsoft Project ensures on-time delivery, while a Sankey diagram visually represents the concept of a circular economy.
FINDINGS: Building information modeling, just-in-time delivery, and circular economy principles maximize demolition planning for efficiency, effectiveness, and sustainability. The green demolition framework serves as a valuable project management tool that enhances planning and resource allocation efficiency, all the while reducing environmental impact through the implementation of selective demolition and enhanced waste management practices.The process completed the demolition of a 6-story building in 88 days, producing 160 cubic meters of reusable waste, eight cubic meters of repairable and refurbishable waste, and 3,972 cubic meters of recyclable wasteThe waste collection for the circular economy is efficiently carried out within a timeframe of 1-2 days, thanks to the implementation of the Just-In-Time delivery schedule.
CONCLUSION: This study delves into advancements in waste management and strategic demolition scheduling. The government should consider the green demolition framework when refining regulations to include Information Communication Technologies and circular economy concepts. Future studies have the potential to improve the green demolition framework by prioritizing environmentally conscious strategies and ensuring effective coordination among all stakeholders involved to achieve the best possible outcomes in demolition projects.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
63	9	3

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INTRODUCTION

Solid waste production reached 2.24 billion tons globally in 2020 (Soto-Paz *et al.*, 2023), with construction and demolition waste (CDW) contributing about 30 percent (%) to 40% (Kabirifar *et al.*, 2020). Wijewickrama *et al.* (2021) stated that 50% of CDW originates from demolition waste, with some estimates reaching up to 90% (Bertino *et al.*, 2021). It is anticipated that the amount of waste will rise as a result of the growing population and urbanization (Soni *et al.*, 2022; Aslam *et al.*, 2020). Developing effective waste management solutions poses a major obstacle due to the ever-changing nature of these approaches, which are closely linked to sustainability, environmental stewardship, and recycling efforts (Weekes *et al.*, 2021) and energy production through various waste-to-energy (WtE) technologies (Malav *et al.*, 2020). Buildings often reach the end of their lifespan and require demolition due to factors like structural aging (Wang *et al.*, 2021), seismic impact (Askarizadeh *et al.*, 2017), alterations of building usage, and urban planning considerations (Huang *et al.*, 2018). Traditional demolition methods involving heavy machinery (Bertino *et al.*, 2021) lead to high carbon emissions (Wang *et al.*, 2018) and mixed waste generation (Tatiya *et al.*, 2018). Deconstruction provides a more sustainable approach as an alternative method.Deconstruction involves the careful disassembly of a building (Kanters *et al.*, 2018), promoting environmentally (Cai and Waldmann, 2019), sustainability (Avelino and Grin, 2017), and circular economy principles by enabling the reuse and recycle of demolition materials (Akanbi *et al.*, 2018). Despite the advantages it offers, deconstruction is not extensively implemented in Indonesia, primarily because there is a lack of comprehensive regulations governing sustainable demolition and post-demolition waste management (Andriyani *et al.*, 2023). A green demolition planning approach is necessary to achieve a circular economy. This approach should function as a comprehensive framework for assessing, regulating, and overseeing projects, thereby playing a pivotal role in enhancing resource efficiency on a broader scale (Sharma *et al.*, 2022). An essential tool for the construction industry's 4.0 industrial revolution, Building information modeling (BIM) provides a foundation for making decisions at every stage of a building's lifespan. The successful execution of BIM plays a pivotal role in ensuring the triumph of a project, spanning from the initial design phase to the eventual demolition stage (You *et al.*, 2020). Application of BIM is considered a breakthrough in infrastructure development, yet has not been widely used in planning the demolition process, particularly in Indonesia (Sopaheluwakan and Adi, 2020). BIM is widely employed in architectural design, prompting the need for more research (Ge *et al.*, 2017). BIM provides advantages in demolition planning by allowing for the simulation of the demolition process sequence using 4D BIM, conducting quantity take-offs from 3D BIM, and facilitating resource planning for material delivery (Won *et al.*, 2017). Further validation is necessary to integrate these functions. BIM has the capability to reduce design modifications, offer visual representations of models, furnish data on possible material reuse and recycling for effective waste management, and enhance knowledge sharing and collaboration among stakeholders (Ganiyu *et al.*, 2020). Application in the demolition phase is crucial. Visualizing the deconstruction sequence on the BIM model can reduce demolition errors and maintain demolition conditions (Elmaraghy *et al.*, 2018). The integration of BIM with lean principles, such as Just-In-Time (JIT), can optimize the design planning process for demolition (Marzouk *et al.*, 2019). This integration offers the ability to swiftly and precisely gather information regarding potential waste and the volume of demolition waste. It also aids in managing batch size and the delivery of building element demolition outcomes, while seamlessly integrating demolition simulation with 4D BIM scheduling (Marzouk *et al.*, 2019). Obtaining waste estimation data during the initial stages of planning will optimize the management approach for the demolition procedur (Wu *et al.*, 2014). The integration of BIM with lean principles, including JIT delivery, often employed in project management during the construction phase, facilitates on-site collaboration, risk mitigation, and productivity enhancement (Likita *et al.*, 2024). Exploring integration in the demolition phase is crucial, especially in the context of a circular economy (Illankoon *et al.*, 2023). The concept of a circular economy, particularly in the realm of waste management, revolves around the ongoing incorporation of construction materials into a secondary life cycle, ultimately prolonging their use and longevity (Purchase *et al.*, 2022). This concept is classified within an R-based framework, which initially consisted of 3R-principle (reduce, reuse, and recycle) (Huang *et al*., 2018), and has evolved into 10R: refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover (Zhang *et al*., 2022). Within the realm of demolition waste, the primary R-based framework that holds significance involves the option of reusing the material if it remains functional and can be utilized without any further processing (Santos *et al*., 2024), repair if the material is damaged (Carvalho *et al*., 2017), refurbishment if the material's function needs to be added (Reike *et al*., 2018), or remanufacture if the material can be transformed into a new product (Ginga *et al*., 2020). The significance of recycling lies in the reprocessing of materials to generate the same material with similar or reduced quality (Alsheyab *et al*., 2022), and will be maximized if waste is separated according to the source or type of material (Arabiyat *et al*., 2024). From a circular economy perspective, the demolition output can be utilized at the micro-level by internal construction projects (Ghisellini *et al*., 2016), at the meso-level by other construction projects or similar industries (Ngan *et al*., 2019), or at the macro-level by other types of industries (Ghisellini *et al*., 2016). The optimization of circular inventory management during demolition planning can enhance the implementation of the circular economy concept at the end of a building's service life. This can be achieved through the prediction of waste information, which can then be shared across different industry sectors (Ding *et al*., 2023). This study stands out due to its innovative approach in effectively managing demolition waste in an environmentally friendly and sustainable manner, by incorporating BIM and JIT delivery into the demolition planning process to promote a circular economy The utilization of BIM and JIT delivery is seamlessly integrated throughout various phases of the project management process: i) The implementation of BIM will provide waste volume estimation data and 3R (reuse, repair or refurbish, and recycling) waste management methods. ii) Integrating 3D BIM and reverse 4D BIM scheduling will effectively plan the demolition sequence of building elements. iii) The demolition schedule outcomes will be integrated with the JIT delivery scheduling strategy to oversee the disposal of demolition waste, which involves waste material processing, organizing delivery sites, and identifying the transportation equipment required to establish a circular economy. Utilizing the findings from managing demolition waste, a sustainable demolition model will be developed based on BIM and JIT delivery to foster a circular economy. The study hypothesis is that integrating waste management into building demolition processes will improve effectiveness, stimulate the circular economy, and uphold environmental sustainability. Indicators of optimal demolition activity include the synchronization of the scheduling sequence in the reverse 4D BIM model and JIT delivery, the coverage of resource capacity such as the number of demolition waste transport equipment and transportation routes, the optimal utilization of demolition waste, and the active circular economy network in utilizing the waste flow. An investigation will be carried out on the implementation of BIM integration, JIT delivery with the circular economy concept, including framework validation on a multi-story building in Jakarta. The current study is focused on creating a demolition process framework tailored for the initial phase of building demolition. This framework is built upon BIM and JIT delivery methods in alignment with circular economy principles. The goal is to ensure that the building demolition process is environmentally friendly, productive, and sustainable. This study was conducted at the Sepuluh Nopember Institute of Technology (ITS) in Surabaya, Indonesia, and the National Research and Innovation Agency (BRIN) in Tangerang Selatan, Indonesia, in 2023.

MATERIALS AND METHODS

This study describes the case study, which provides an overview of the building's characteristics, functions, size, surrounding environment, and the specific building elements to be modeled in three dimensions. The study also provides a comprehensive overview of the research framework employed, focusing on integrating digital technology, JIT delivery concepts, and circular economy principles within the context of demolition waste management. Utilizing methodologies like 3D BIM and QTO analysis, the structural and material components of the building were evaluated. Reverse 4D BIM techniques were then used to effectively sequence demolition activities, guaranteeing maximum efficiency and safety precautions. JIT delivery scheduling strategies were implemented to manage demolition waste in a timely and coordinated manner. The principles of the circular economy have shaped the approach to waste management, prioritizing the recovery of resources, their reuse, and the implementation of sustainable disposal methods.

Case study

The study focuses on a 5-story reinforced concrete building, also known as a 6-floor structure, that has been in existence for 19 years. It serves as either a residence or a basic rental apartment. This building, located in Cilincing, North Jakarta, DKI Jakarta, Indonesia, has a floor area of approximately 904,858 m^2 per floor with 20 residential units, each measuring 30 m^2. The first level of the building functions as a prayer room, a shop, and a space for gatherings. The residential areas are located on floors 1 to 5, and the roof is situated on the 6th story. The buildings chosen for the case study are part of a complex consisting of five similar 6-storey structures that are positioned next to one another. The urban landscape consists of housing communities, business establishments, and greenery along the main road to ensure smooth traffic flow. This building will subsequently be modeled into three dimensions using digital BIM technology, referred to as a 3D BIM model. Furthermore, the structure will also undergo a modeling process to simulate the demolition sequence of its components. This simulation, known as a reverse 4D BIM model, will start from the top floor and progress downwards until reaching the ground floor (Adi and Andriyani, 2023). 3D BIM modeling is limited to architectural and structural models and excludes mechanical, electrical, and plumbing models. Architectural building elements in the building that are included in the model to be planned for demolition include doors, windows, walls, and iron railings. In contrast, structural building elements made of reinforced concrete include floor slabs, beams, columns, and stairs. The floor plan and building facade serve as the foundation for the 3D modeling of the building's structure.

Integrating digital technology of BIM, JIT delivery concept and circular economy

This study combines digital technology BIM, JIT delivery concept, and circular economy principles using different software. Autodesk Revit is utilized to generate parametric 3D models, encompassing architectural models, intricate framing structures, and quantification of demolition waste (Shi *et al.*, 2021). This model is imported into Navisworks for 4D BIM modeling (Jupp *et al.*, 2017), which includes demolition scheduling and visualization. Navisworks, which links the project schedule with the 3D BIM model, facilitates planning and coordination (Martins *et al.*, 2022). Microsoft Project is utilized for project management, including demolition scheduling and time analysis The demolition planning model incorporates JIT delivery and circular economy principles. JIT delivery is implemented in scheduling, while the circular economy is illustrated with a Sankey diagram.

3D BIM and QTO

BIM handles digital data from the planning stage to the demolition stage, encompassing all of a building's physical and valuable features (Volk *et al.*, 2018). To commence the creation of a 3D BIM model, it is necessary to compile pertinent technical building data, encompassing as-built drawings, building plans, building views, structural systems, and material information pertaining to architectural and structural building elements. The data and information are utilized to generate a digital representation of the building (Andriyani *et al.*, 2023). 3D modeling is customized to the building design and perspective and is carried out independently for the structure and architecture. Modeled structural and architectural elements are equipped with material specification information, 3R waste management plans, and demolition sequence plans for elements. he 3D BIM model processes the data and information inputted into it, automatically generating volumes according to the selected materials and specifications in the QTO process via the schedule or material QTO feature (Monteiro *et al.*, 2013). The title of the QTO tabulation is selected in the schedule property menu; examples are volume, material type, dimensions, and floor location. The results of the QTO tabulation can be extracted and analyzed in Microsoft Excel for further analysis.

Reverse 4D BIM for demolition sequence

The demolition process is the reverse of the construction process; building elements are demolished from the top down to the base (Kanters

Table 1: Waste volume factor exchange () (Kim *et al.*, 2017)

Waste type	Waste volume factor exchange
Concrete waste	1.1
Metal waste	1.02
Wood waste	1.05
Glass waste	1.05
Brick waste	1.25
Others	1.0

et al., 2018). The 3D BIM model encompasses the geometry, material, specifications, and volume of the structural and architectural building elements being demolished. 4D BIM is a modeling process that integrates the time dimension into the 3D BIM model. Initiate the modeling process by establishing a timetable for the order in which elements will be demolished, as depicted in the 3D BIM model (Martins *et al.*, 2022). The duration of the demolition, the start and end dates of the demolition process, the sequence of building elements to be demolished, and the timing of the demolition activities for each element can be inputted directly into the 4D BIM modeling or created separately using other project scheduling software (Doukari *et al.*, 2022). The establishment of a dataset containing the building elements to be demolished in the 3D BIM model should be linked to the previously developed schedule. The demolition scheduling procedure involves dismantling the building elements in a top-to-bottom manner, resembling the inverse principle in construction, commonly referred to as the reversed 4D BIM concept.

JIT delivery scheduling for demolition waste management

JIT delivery is a logistics management philosophy that enhances resource productivity effectiveness and reduces waste, ensuring that demolition waste is promptly transported and delivered at the right time and location (Andriyani *et al.*, 2023). This concept also prevents the long-term accumulation and storage of demolition waste, which has the potential to mix back and degrade its quality. Implementing JIT delivery in planning generates a timeline for the removal of demolition waste, commencing from the demolition phase to the final delivery at the designated site. The input data in the JIT process are the specifications and volume of demolition waste from QTO, while the sequence schedule comes from 4D BIM. According to research by Kim *et al.* (2017), the volume of specific dismantling material will expand, as it does not form a single mass, so the volume from QTO BIM ($V_{QTO\ BIM}$) will be multiplied by the waste volume factor exchange (F_{wvc}) as Table 1, becoming the factored demolition waste volume (V_f), using Eq. 1 (Su *et al.*, 2021). The waste volume factor exchange values selection is adjusted according to the type of demolition waste; for building elements made of concrete, the value used is 1.1; for elements with metal material, the value is 1.02; for wooden elements, the value is 1.05; for elements containing glass material, the value is 1.05; and for brick material waste, the value is 1.25. Other types of waste materials are assigned a value of 1.

$$V_f = V_{QTO\ BIM}\ x\ F_{wvc} \quad (1)$$

The anticipated number of trucks essential for transporting goods to the designated destination can provide an indication of the time needed to deliver the ensuing demolition outcomes.In Indonesia, small trucks (pick-up) and dump trucks are commonly used for transportation in construction and demolition projects. Small trucks have a maximum volume capacity (V_{truck}) of 8 cubic meters (m^3), while dump trucks can carry up to 20 m^3. There are also dump truck trailers available with a larger capacity of 40 m^3, but these are typically designed for use in rugged terrain. The equation for calculating the trucks needed (N_{truck}), using Eq. 2 (Su *et al.*, 2021):

$$N_{truck} = \frac{V_f}{V_{truck}} \quad (2)$$

Circular economy for demolition waste management

Demolition waste materials from building elements can be identified and planned for 3R waste generation

Table 2: CDW's type and possibility of recycling (Yeheyis *et al.*, 2013)

The waste component from CDW	The potential to be used in several ways
Concrete	Concrete waste for building roads, fly ash production (additive materials for concrete), recycling concrete aggregate
Steel	Utilized in construction and many industries, recyclable steel
Brick and block	Utilized for construction purposes, backfilling, and as recycled aggregate
Glass	recycled crushed glass in road pavements, a replacement for natural aggregates and cement
Ceramic	As an aggregate for concrete and fill materials
Aluminum	Utilized in secondary aluminum manufacturing
Wood	Utilized in paper and pulp industries to manufacture new board and partition tiles
Gypsum board	Concrete waste for building roads, fly ash production (additive materials for concrete)

utilization since the 3D BIM modeling stage; this stage is called waste potential inventory. The initial phase of incorporating BIM with the circular economy is the inventory stage of the 3R waste potential. The circular economy's R framework for waste generation in the 3R approach includes reuse, repair or refurbishment, and recycling. This framework plays a crucial role in the circular building life cycle, where buildings function as material stock and their life cycle symbolizes circulation (Çimen, 2023). The delivery location is determined based on the 3R management plan and the waste volume data obtained from the QTO BIM analysis. These delivery locations, encompassing micro, meso, and macro scales, are adjusted according to the 3R management plan, as shown in Table 2. The integration of BIM with the circular economy involves the inclusion of QTO BIM waste estimation results to determine the delivery location for 3R waste utilization and management. The demolition technique will be influenced by the tailored demolition results that cater to consumer needs, thereby making the process of building demolition resemble the production process of demolition waste with reverse logistics management. (Chen and Liao, 2022). As a result, the structure of the building becomes a repository for materials (Cai and Waldmann, 2019). The flow of demolition waste, beginning with the estimated waste volume categorized by the 3R classification in BIM, the final adjusted volume delivered to a specific location, and the overall volume to be transported based on the truck type, can be illustrated using a Sankey diagram.

RESULTS AND DISCUSSION

The study presents the outcomes of the study's multifaceted approach in leveraging digital technologies and innovative methodologies for advancing demolition waste management within the green demolition framework. The subsections explore the outcomes derived from various elements of the approach, encompassing 3D BIM modeling, QTO analysis, reverse 4D BIM for demolition sequencing, JIT delivery scheduling for efficient waste management, and the consequences of circular economy principles. Each subsection offers insights into the effectiveness and applicability of these methodologies in optimizing resource utilization and minimizing waste generation throughout the demolition process. Within the green demolition framework development section, the outcomes of incorporating BIM and JIT delivery scheduling into demolition planning are examined. The objective is to foster a circular economy, and this integration plays a crucial role in the establishment of the green demolition framework. The objective is to elucidate the fusion and obstacles of merging digital technology, JIT delivery scheduling, and circular economy concepts with green demolition principles to enhance sustainability in the construction industry.

3D BIM result

Autodesk Revit software was utilized to generate a 3D BIM model for a 6-story building as part of the investigation. This measure was implemented to gain a thorough understanding of the architecture and elements of the building within a digital setting. The process was initiated by importing 2D floor plan drawings into the BIM program, a method previously demonstrated by Gimenez *et al.* (2015), aiming to accurately represent the building's layout and features in three dimensions. The 3D model encompasses every floor of the building, outlining the level or height of each floor within the model. The structural elements of the building in the 3D BIM model are made separately from the architectural

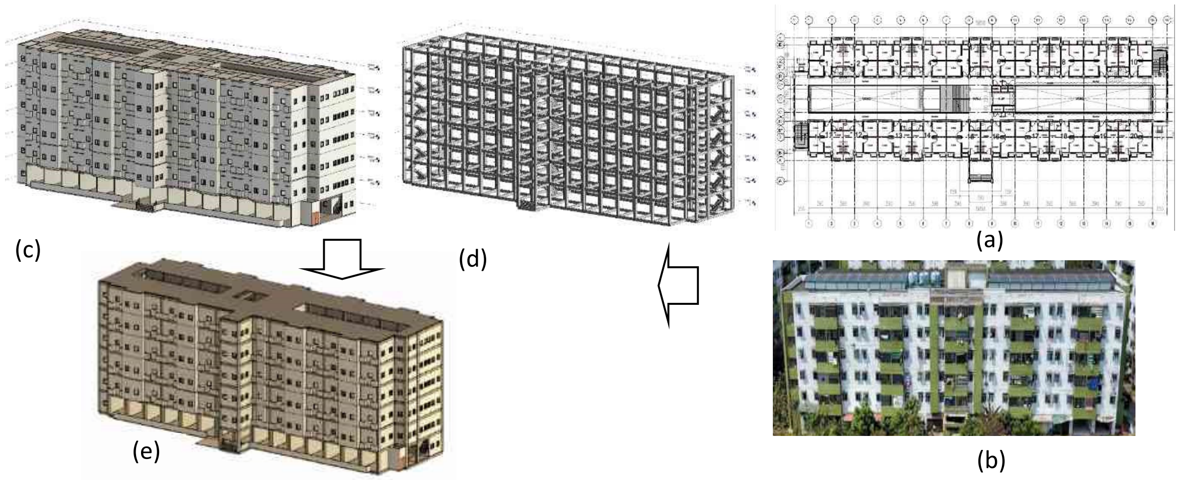


Fig. 1: 3D BIM modeling process, floor plan drawing (a), picture of the case study building (b), 3D BIM architecture model (c), 3D BIM structure model (d), combined 3D BIM model (e).

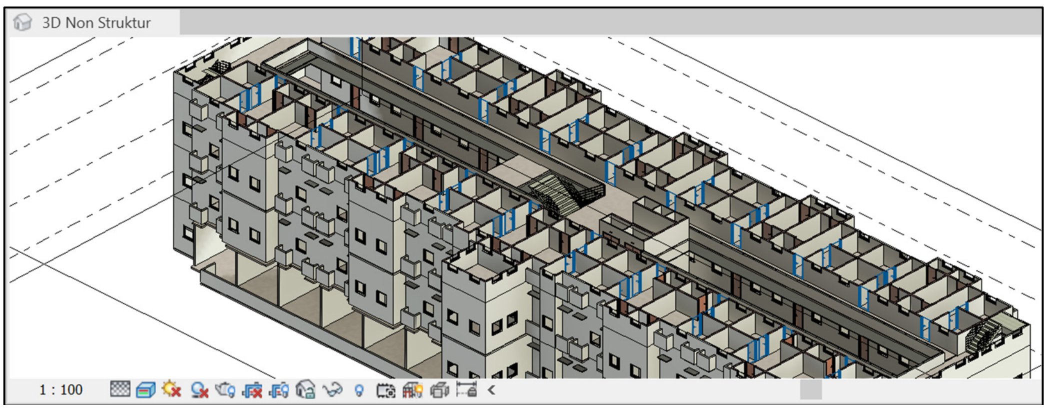


Fig. 2: Tracking the position of building elements in the 3D BIM model

elements (Fig. 1), ensuring a detailed and accurate representation of the building's composition. The process of completing the 3D BIM modeling stage encompasses the crucial tasks of establishing the material requirements for every building component and identifying any potential waste that aligns with the 3R concept. These steps are fundamental as they greatly influence the subsequent QTO findings. This extensive digital depiction establishes the groundwork for additional analysis and decision-making concerning the planning of demolition, facilitating effective management of resources and strategies for reducing waste.

QTO BIM result

QTO in 3D BIM automatically extracts data such as location, element category, material type, dimensions, waste volume, and the count of structural and architectural elements, which is displayed as a QTO tabulation. The QTO tabulation further encompasses the succession of demolition phase plans as well as waste management plans, which involve reuse, repair, refurbishment, and recycling. The plans may stem from consumer needs, architectural blueprints, or construction material categories. Tracking building elements in the QTO table facilitates the organization of demolition priorities (Fig. 2). The QTO results are then extracted to Microsoft Excel for calculations such as factored demolition waste volume, truck number estimation for JIT delivery scheduling, and circular economy modeling. Table 3 will showcase the outcomes derived from these computations.

Table 3: Recapitulation of QTO 3D BIM tabulation, factored waste volume, number of trucks

No	Element category	Material	Waste management for the circular economy's strategy (3R)	Demolition waste 3R volume from QTO BIM							Total demolition waste from QTO BIM			Total demolition waste with volume change factor		Number of truck (N_{truck})	
				Level 0	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Total (3R)		volume (m^3)	Waste volume change factor (F_{wvc})	Factored demolition waste volume (V_f) (m^3)	Volume truck (V_{truck}) maks 20 m^3	Volume truck (V_{truck}) maks 8 m^3
1	Windows	Aluminum and glass	Reuse	37	109	100	98	90	109	-	543	unit	22,2	1,05	23	1	0
		Aluminum and glass	Repair	0	0	9	9	14	0	-	32	unit	1,3	1,05	1	0	1
		Aluminum and glass	Refurbish	0	0	0	2	5	0	-	7	unit	0,3	1,05	0	0	0
			Recycle	0	0	0	0	0	0	-	0		0,0	1,05	0	0	0
				37	**109**	**109**	**109**	**109**	**109**		**582**	unit	**23,8**	1,05	**25**	**1**	**1**
2	Door	Wood	Reuse	8	58	54	61	61	63	-	305	unit	28,4	1,05	30	2	0
	315	Wood	Repair	4	0	0	0	2	0	-	6	unit	0,6	1,05	1	0	0
	29,38	Wood	Refurbish	0	0	1	2	0	0	-	3	unit	0,3	1,05	0	0	0
	0,09327	Wood	Recycle	1	0	0	0	0	0	-	1	unit	0,1	1,05	0	0	0
				13	**58**	**55**	**63**	**63**	**63**		**315**		**29,4**	**1,05**	**31**	**2**	**0**
		aluminum	Reuse	5	0	0	0	0	0	-	5	unit	0,5	1,00	1	0	0
		aluminum	Repair	3	0	0	0	0	0	-	3	unit	0,3	1,00	0	0	0
		aluminum	Refurbish	0	0	0	0	0	0	-	0		0,0	1,00	0	0	0
		aluminum	Recycle	0	25	28	20	20	20	-	113	unit	11,6	1,00	12	0	2
				8	**25**	**28**	**20**	**20**	**20**		**121**	unit	**12,4**	**1,00**	**12**	**0**	**2**
		PVC	Reuse	0	0	0	0	0	20	-	20	unit	1,9	1,00	2	0	1
		PVC	Repair	0	0	0	0	0	0	-	0		0,0	1,00	0	0	0
		PVC	Refurbish	4	0	20		20	0	-	44	unit	4,2	1,00	4	0	0
		PVC	Recycle	0	20	0	20	0	0	-	40	unit	3,8	1,00	4	0	1
				4	**20**	**20**	**20**	**20**	**20**		**104**	unit	**9,9**	**1,00**	**10**	**0**	**2**
3	Railing	steel	Reuse	56	107	165	165	165	115	-	773	m'	3,9	1,02	4	0	1
		steel	Repair		58	0	0	0	51	-	109	m'	0,5	1,02	1	0	0
				56	**165**	**165**	**165**	**165**	**165**		**882**	m'	**4,4**	**1,02**	**5**	**0**	**1**
4	Wall	Brick	Recycle	**159**	**408**	**408**	**408**	**408**	**408**	-	**2199**	**m^3**	**2198,8**	**1,25**	**2000**	**100**	**0**
			Landfill												**419**	**21**	**0**
		Partition	Recycle	**4**	**4**	**4**	**4**	**4**	**4**	-	**22**	**m^3**	**22,0**	**1,10**	**22**	**1**	**0**
		Concrete	Recycle	**10**	**5**	**5**	**5**	**5**	**5**	-	**33**	**m^3**	**33,4**	**1,10**	**37**	**2**	**0**
5	Floor	Concrete	Recycle	**144**	**109**	**111**	**109**	**109**	**110**	**110**	**801**	**m^3**	**801,0**	**1,10**	**881**	**44**	**0**
		Reinforcement steel	Recycle	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**8**	**m^3**	**8,0**	**1,02**	**8**	**0**	**1**
		Ceramic	Reuse	**0**	**27**	**28**	**28**	**28**	**28**	-	**137**	**m^3**	**137,4**	**1,10**	**100**	**5**	**0**
															51	**3**	
6	Beam	Concrete	Recycle	**55**	**49**	**49**	**49**	**49**	**49**	**49**	**346**	**m^3**	**345,7**	**1,10**	**380**	**19**	**0**
		Reinforcement steel	Recycle	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**9**	**m^3**	**8,6**	**1,02**	**9**	**0**	**1**
7	Column	Concrete	Recycle	**140**	**70**	**70**	**70**	**70**	**70**	-	**491**	**m^3**	**490,6**	**1,10**	**540**	**27**	**0**
		Reinforcement steel	Recycle	**5**	**2**	**2**	**2**	**2**	**2**	-	**17**	**m^3**	**16,6**	**1,02**	**17**	**1**	**0**
8	Stair	Concrete	Recycle	**19**	**9**	**9**	**9**	**9**	-	-	**56**	**m^3**	**56,5**	**1,10**	**62**	**3**	**0**
		Reinforcement steel	Recycle	**0,37**	**0,18**	**0,18**	**0,18**	**0,18**	-	-	**1,07**	**m^3**	**1,0**	**1,02**	**1**	**0**	**1**

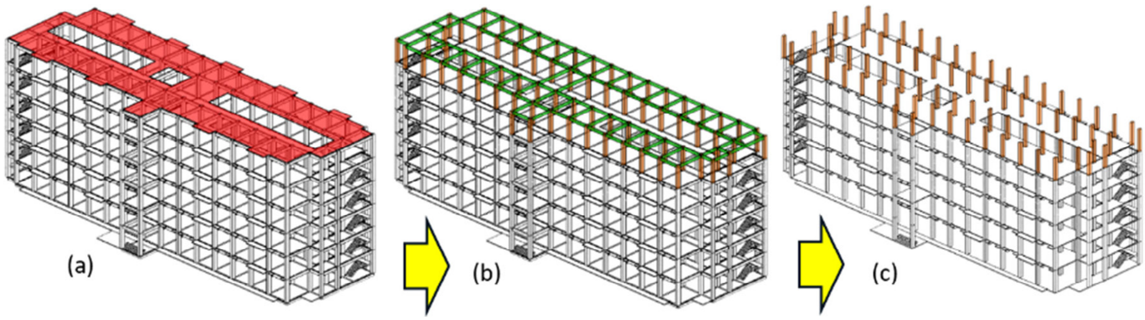


Fig. 3: (a) Pattern of demolition sequence of structural elements of floor plates, (b) beams, and (c) columns.

The architectural demolition elements to be reused in the most significant volume are wooden doors (28 m^3 or 305 units), while bricks (2,200 m^3) will be recycled. The most significant volume of demolition to be repaired or refurbished is PVC (Polyvinyl chloride) doors (44 units or 4.2 m^3 out of 104). The structural demolition elements to be recycled are mainly concrete and reinforcement, with the most significant volumes being floor plates (801 m^3 out of 1,727 m^3) and columns (17 m^3 out of 34 m^3). QTO has been efficiently employed to estimate the waste generated by building components, allowing for a comprehensive evaluation of their potential for reuse, repair, refurbishment, or recycling. The QTO information is used to create demolition phase plans and waste management strategies, enhancing the efficiency and sustainability of the demolition process. Valinejadshoubi *et al.* (2020) have shown that QTO findings are accurate and useful in detecting volume differences that might lead to waste during changes in building planning design. Kim *et al.* (2017) have utilized BIM to accurately forecast the quantity of waste by employing QTO, with waste concrete emerging as the predominant form of waste. This study demonstrates that the use of QTO may be expanded to include activities such as labelling and designing waste (Akinade *et al.,* 2018), prospective waste classification, and determining demolition phase sequences.

Reverse 4D BIM result

4D BIM modeling is performed using Navisworks, which is interoperable with Autodesk Revit. The direct import of the 3D BIM model from Autodesk Revit into Navisworks is made possible through interoperability. The demolition is scheduled will commence in a reverse order of construction, beginning from level 6 and moving downwards to level 0, in accordance with the principles of the reverse 4D BIM concept. Fig. 3 depicts the progression of demolition stages on every floor for the primary structural components, initiating with the removal of the red-colored floor plate spanning two days. The green beams will be demolished over three days, while the orange columns will be removed over four days for each level. The process of dismantling the wall will take a total of two days after the removal of the floor plate has been completed. Simultaneously, the staircase disassembly will also be carried out, which will require two days to complete and will be done in conjunction with the beam disassembly. The architectural components demolition plan involves the removal of windows, doors, staircase and corridor wall railings, and ceramic floor starting from level 5 and progressing downwards to level 0. This sequence will take place over a span of four, four, three, and two days.

Reverse 4D BIM employed for the purpose of strategizing the demolition of a structure, encompassing three primary stages. Initially, a dataset of demolishing building elements is created by selecting elements from the 3D BIM model. Subsequently, the scheduling of reverse 4D BIM entails determining the commencement and completion dates for each demolition task, starting from the highest building elements down to the most fundamental ones. This scheduling considers the anticipated duration of work and the interdependencies among different demolition activities. Moreover, this scheduling is compatible with Naviswork and can be seamlessly imported into the timeline feature using Microsoft Excel, Microsoft Project, or Primavera. The QTO results from the

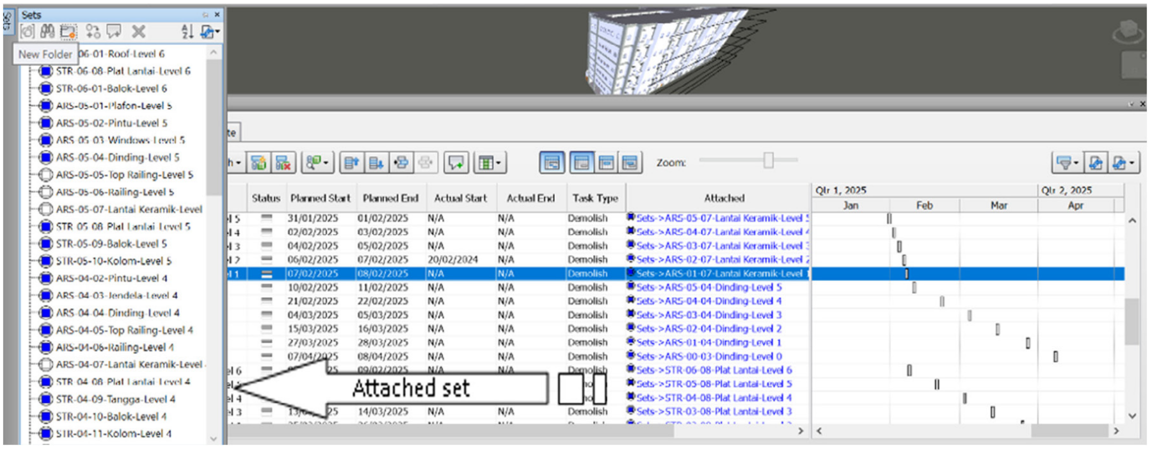


Fig. 4: Dismantling scheduling adjusted to the sequence of building elements dismantled

demolished elements become essential information in planning 4D BIM scheduling. The demolition sequence is designed to prioritize the quality of demolition results and consider environmental impact factors, distance to surrounding buildings, and worker safety. The demolition of buildings may lead to dust and particles, which can adversely affect air quality. Demolition activities can also result in the generation of excessive noise pollution and vibrations that can impact nearby structures (Ding *et al.*, 2016). Third, the job type on the TimeLiner feature is selected as 'demolish,' and the scheduled demolition work is linked with the dataset of building elements to be demolished (Fig. 4).

The final step is visualizing the reverse 4D BIM simulation of the building element demolition process. This simulation can move and be extracted into a video file. In the simulation, elements that are meant to be demolished are automatically highlighted in red. If the red color disappears, it indicates that the building element has been destroyed. The results of the reverse 4D BIM demolition simulation for windows and doors, as well as the structural part on the 5th floor according to the planned sequence, and the final two demolition activities on the ground floor are shown in Fig. 5. The demolition process is scheduled to last 88 days, with work scheduled for all 7 days of the week. The ability to input actual start and finish dates for the demolition is available for future implementation, enabling this reverse 4D BIM to evaluate the process and quality of the demolition. 4D BIM tools, commonly employed in construction planning to enhance efficiency, have been successfully applied to sequence demolition processes through reverse scheduling. The emphasis on utilizing reverse 4D BIM for planning demolition activities involves creating a dataset for demolishing building elements, scheduling demolition tasks, and visualizing the process through simulation. Demolition planning focuses on achieving top-notch demolition results while taking into account environmental aspects and the safety of workers. The visualization aspect of simulation results allows for dynamic adjustments and video extraction, adding an innovative dimension to the methodology. Through the simulation, a complete understanding and evaluation of the demolition process is assured. Selective demolition planning, prioritizing the dismantling of reusable components followed by those suitable for repair or refurbishment, and finally, the demolition of recyclable elements serves to maximize material conservation (Guerra *et al.*, 2020), while simultaneously addressing risk mitigation in planning (Sloot *et al.*, 2019).

JIT delivery scheduling for demolition waste management result

The successful implementation of JIT delivery scheduling relies on accurate data regarding the total volume of 3R waste for each building element, as well as the scheduling of reverse 4D BIM. The reverse 4D BIM encompasses the duration, start date, and end date of the demolition activities for building components. By effectively coordinating

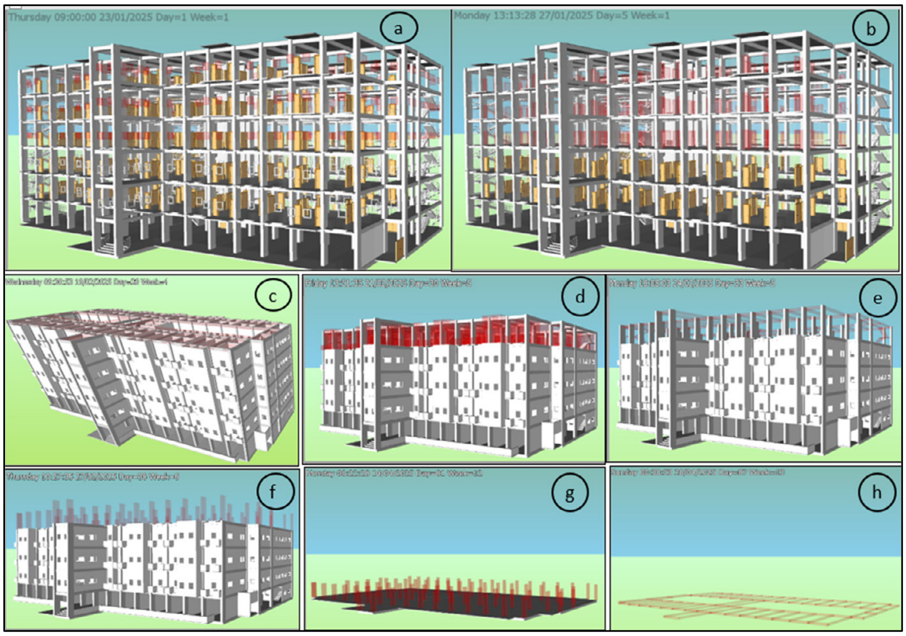
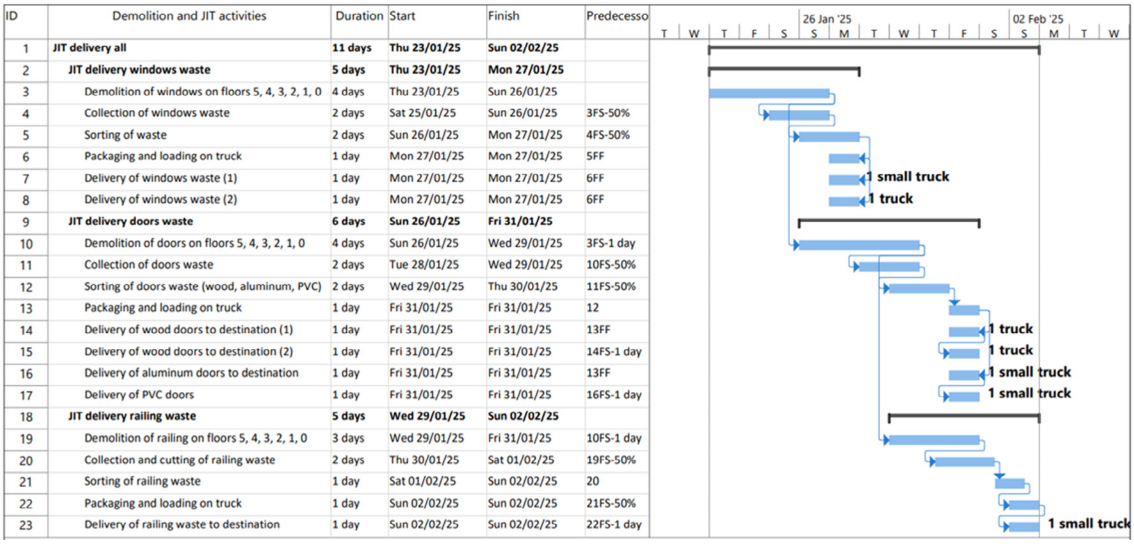


Fig. 5: Integrated sequencing of architectural demolition (marked in red) on the 5, 4, 3 floors, (a) window, (b) door; and sequencing structural demolition on the 5th floor (marked in red), (c) floor structure, (d) wall, (e) beam structure and stair, (f) column structure, and demolition on base floor, (g) column structure, (h) beam structure (printed screen 4D BIM from Naviswork)

waste delivery with the planned demolition schedule, this approach aims to optimize waste management efficiency. The JIT delivery schedule is adjusted according to the demolition sequence, and the activities of one JIT delivery cycle include demolition, collection, sorting, packaging, and loading to the truck, then waste delivery. To efficiently manage waste delivery operations, it is crucial to have accurate information regarding the quantity and capacity of transport vehicles. This data is derived by dividing the volume of demolition waste by the volume of each transport vehicle. The option utilized for this study is a small truck with a maximum capacity of 8 m3 or a dump truck with a maximum capacity of 20 m^3. The total number of trucks for 3R waste from each building element is seen in Table 3. Fig. 6 is the scheduling of one cycle of JIT delivery for windows, doors, and railing waste; as an example of JIT delivery scheduling of 25 m^3 of level 5-0 window elements, requiring transport of one truck and one small truck, resulting in a total duration of 5 days from the start of demolition. This task comprises of a four-day window demolition process, followed by a two-day window waste collection phase that commences once 50% of the demolition work is completed. After that, there are two days allocated for waste sorting, which begins after 50% of the window waste collection work. Finally, there is one day dedicated to packaging and loading the waste onto trucks. To ensure efficiency, the delivery of window waste is conducted using one truck and one small truck simultaneously, with the aim of completing both tasks on the same day. The next demolition phase is the demolition of 31 m^3 wooden doors, 12 m^3 aluminum doors, and 10 m^3 PVC doors, which last four days. The start date for door collection is determined after 50% of door demolition has occurred over two days. Before 50% of the door collection work is completed, the sorting work of the door demolition results begins. On the final day of organizing the demolition outcomes, the process of packaging and loading onto trucks for transportation to the intended location is repeated twice, with the option of using either a single truck or a small truck for hauling. The JIT delivery schedule shows that the operations, from collection to waste delivery, can be completed in 1-2 days by starting collection after 50% progress of demolition and increasing the number of transport trucks. The purpose is to establish a reliable and proficient waste transport system that operates efficiently and



ID	Demolition and JIT activities	Duration	Start	Finish	Predecessors
1	**JIT delivery all**	**11 days**	**Thu 23/01/25**	**Sun 02/02/25**	
2	**JIT delivery windows waste**	**5 days**	**Thu 23/01/25**	**Mon 27/01/25**	
3	Demolition of windows on floors 5, 4, 3, 2, 1, 0	4 days	Thu 23/01/25	Sun 26/01/25	
4	Collection of windows waste	2 days	Sat 25/01/25	Sun 26/01/25	3FS-50%
5	Sorting of waste	2 days	Sun 26/01/25	Mon 27/01/25	4FS-50%
6	Packaging and loading on truck	1 day	Mon 27/01/25	Mon 27/01/25	5FF
7	Delivery of windows waste (1)	1 day	Mon 27/01/25	Mon 27/01/25	6FF
8	Delivery of windows waste (2)	1 day	Mon 27/01/25	Mon 27/01/25	6FF
9	**JIT delivery doors waste**	**6 days**	**Sun 26/01/25**	**Fri 31/01/25**	
10	Demolition of doors on floors 5, 4, 3, 2, 1, 0	4 days	Sun 26/01/25	Wed 29/01/25	3FS-1 day
11	Collection of doors waste	2 days	Tue 28/01/25	Wed 29/01/25	10FS-50%
12	Sorting of doors waste (wood, aluminum, PVC)	2 days	Wed 29/01/25	Thu 30/01/25	11FS-50%
13	Packaging and loading on truck	1 day	Fri 31/01/25	Fri 31/01/25	12
14	Delivery of wood doors to destination (1)	1 day	Fri 31/01/25	Fri 31/01/25	13FF
15	Delivery of wood doors to destination (2)	1 day	Fri 31/01/25	Fri 31/01/25	14FS-1 day
16	Delivery of aluminum doors to destination	1 day	Fri 31/01/25	Fri 31/01/25	13FF
17	Delivery of PVC doors	1 day	Fri 31/01/25	Fri 31/01/25	16FS-1 day
18	**JIT delivery railing waste**	**5 days**	**Wed 29/01/25**	**Sun 02/02/25**	
19	Demolition of railing on floors 5, 4, 3, 2, 1, 0	3 days	Wed 29/01/25	Fri 31/01/25	10FS-1 day
20	Collection and cutting of railing waste	2 days	Thu 30/01/25	Sat 01/02/25	19FS-50%
21	Sorting of railing waste	1 day	Sat 01/02/25	Sun 02/02/25	20
22	Packaging and loading on truck	1 day	Sun 02/02/25	Sun 02/02/25	21FS-50%
23	Delivery of railing waste to destination	1 day	Sun 02/02/25	Sun 02/02/25	22FS-1 day

Fig. 6: JIT delivery scheduling for the results of dismantling windows, doors, and railings

effectively as per the specified timetable. Additional manpower is necessary for the waste sorting stage in order to expedite and improve the accuracy of the process, thereby opening up employment opportunities within the community (Arabiyat *et al.*, 2024). In terms of time management, the scheduling of JIT delivery in demolition is influenced by the start time of the demolition process. This allows for predicting the start time of collection work after 50% of the demolition progress is completed. The number of transport equipment for delivery also influences this. Efficient planning of both transport equipment quantity and JIT delivery scheduling can be derived from the estimated volume obtained through BIM. This is contrasted with Kong *et al.* (2018), research on the construction project of installing precast concrete, where JIT delivery is influenced by the transportation time of material delivery from the factory to the project location and the installation time. The longer the delivery time, the more strategies are needed for temporary material stacking, which is arranged according to the installation location. The JIT approach is a management strategy aimed at minimizing inefficiencies stemming from overproduction, idle time, transportation, surplus inventory, and defective items. Substantial improvements in sustainable performance can be attained by incorporating the JIT philosophy into the proposed strategy for scheduling large quantities of deliveries (Kong *et al.*,2018). Radio Frequency Identification (RFID) technology facilitated the identification of manufacturing components from the factory during installation in the project and temporary storage locations (Li *et al.*, 2017). The utilization of BIM technology in the demolition process is comparable to the approach used in scheduling and planning demolition activities in a sequential manner. By incorporating transportation equipment and human resources into these processes, it is possible to enhance overall time efficiency in both areas of study. JIT delivery in demolition versus precast construction presents unique challenges and opportunities for efficiency.

Circular economy

The data from the QTO 3D BIM results, which include the volume of building elements that can be reused, repaired, refurbished, and recycled as shown in Table 3, are used as input for circular economic modeling. This data determines the transportation destination for potential demolition waste management. Data from the JIT delivery schedule, including delivery duration and fleet quantity, are integrated to determine alternative destination locations, travel time, and delivery distance. The objective is to avoid any disruptions to the demolition timeline caused by the delivery and streamline the process of sorting demolition materials on site.The factored waste volume for each dismantled building element and the choice of means of transportation are sourced from QTO 3D BIM (Table 3), followed by the drop-off destination for sending the waste (second-hand shops, wood consumers, concrete factory, recycler facilitator, construction project, brick factory, landfill), then displayed in a Sankey diagram as a circular economy result, shown in Fig. 7. According to Fig. 7, most of the demolition that can be reused, repaired, and refurbished from levels 0 to 5 consist of architectural elements that can be repurposed, fixed, or renovated for various purposes. The total volume of factored waste that can be reused includes aluminum glass windows 23 m^3, wood doors 30 m^3, aluminum doors 1 m^3, PVC doors 2 m^3, steel railings 4 m^3, and ceramic 151 m^3. The total volume of factored waste for repaired and refurbished elements includes aluminum glass window 2 m^3, wood door 1 m^3, PVC door 4 m^3, and steel railing 1 m^3. The second-hand shop will receive a total of 32 m^3 of these items, while the wood consumer will receive 1 m^3. Additionally, 5 m^3 will be allocated for other construction projects. According to Fig. 7, The results of the demolition that can be recycled for a total from level 0 to 6 include aluminum door 12 m^3, PVC 4 m^3, brick wall 2,000 m^3, partition wall 22 m^3, concrete wall 37 m^3, concrete floor 881 m^3, concrete beam 380 m^3, concrete column 540 m^3, and concrete stair 62 m^3. In addition, 35 m^3 of steel reinforcement steel is sent entirely to the steel factory. The composition of the number of transport vehicles used includes 1 unit of a dump truck 20 m^3 and 1 unit of a small truck 8 m^3 with a total truck transport volume of 4,560 m^3, requiring 228 hauling routes. The total transport volume of the small truck is 51 m^3 for six hauling routes. The integration of data input from multiple trucks is essential for JIT delivery scheduling. For instance, in the demolition process using 4D BIM, the sequence involves windows, doors, and steel railings. To ensure just-in-time delivery, the window and railing demolitions are carried out separately using one truck each, while a small truck transports them to the second-hand shop. This process is referred to as a hauling route. JIT delivery of door demolition requires two hauling routes, even though one truck and one small truck to the second-hand shop at the same time. The implementation of the circular economy (CE) model, as conceptualized to maximize resource efficiency, minimize waste generation, and promote material reuse, repair, refurbishment, and recycling throughout their lifecycle (Blomsma *et al.,* 2020), is illustrated in Fig. 7. The assessment shows a distinct favor for recycling concrete items rather than reusing them. This emphasizes the importance of maximizing the value of recycled waste through suitable management strategies (Ghisellini *et al.,* 2016) and well-planned dismantling methods (Haas *et al.,* 2015). Issuing certificates for the final recycled aggregate ensures quality assurance, boosting public trust in the demolition outcomes and enhancing the economic value of the resulting products (Silva *et al.,* 2017). Enhancing sustainability and efficiency in urban development and construction projects greatly depends on the integration of circular economy principles with innovative approaches such as BIM and JIT delivery scheduling. The circular economy model addresses the economic feasibility and cost implications associated with implementing this integrated approach by leveraging empirical data from QTO 3D BIM results and JIT delivery scheduling. The empirical findings provide insights into the volume of building elements that can be reused, repaired, refurbished, and recycled, as well as the transportation logistics involved in managing demolition waste, as shown in Fig. 7. In real-world urban development projects, the circular economy model assesses the economic feasibility of circular economy practices by analyzing the economic viability of transporting salvaged materials to different destinations, including second-hand shops, wood consumers, construction projects, and recycling facilities.

Green demolition planning framework development

The exploration of integrating BIM and JIT delivery towards a circular economy in building demolition planning applied to a case study of a 6-story building can be presented into a workflow framework, as shown in Fig. 8. This framework for demolition planning is utilized to construct and establish an environmentally-friendly demolition framework (Fig. 9). Within the green demolition framework, there is a focus on strategically planning demolition activities. Implement efficient organization of demolition tasks to enhance material conservation through automated processes that can identify potential waste types and quantities. Planned sequence and schedule for selective disassembly of components that can be recycled and repurposed to reduce environmental impacts. Strategic waste utilization planning for a circular

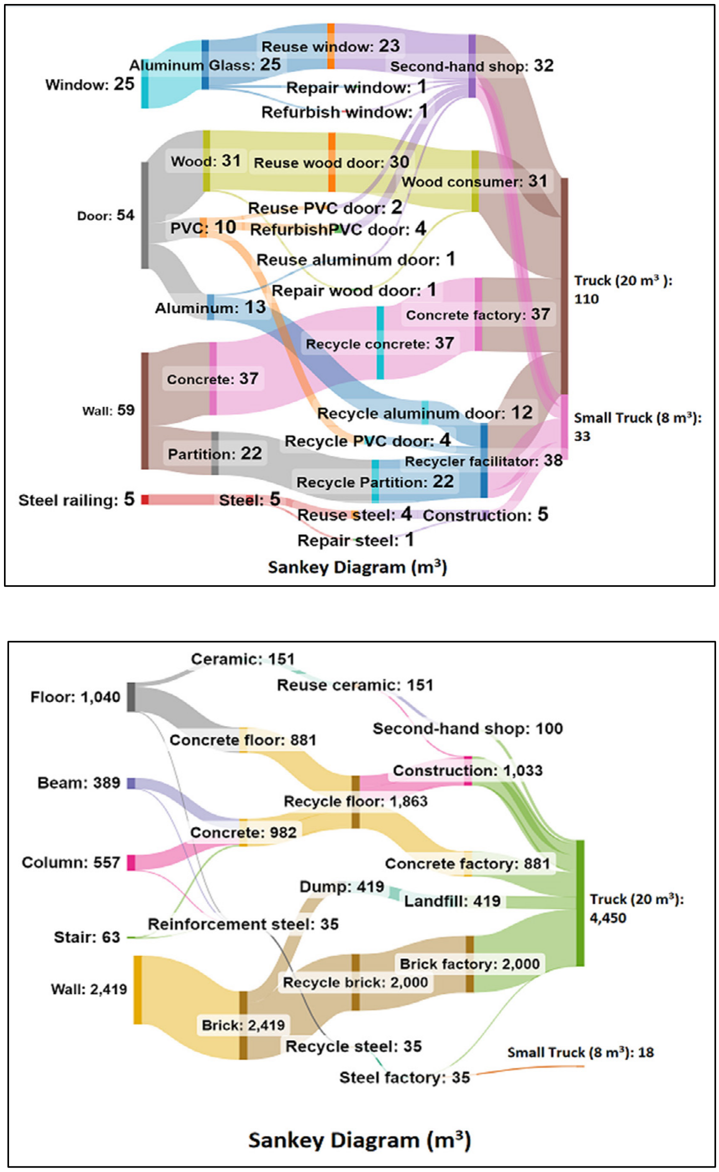


Fig. 7: Circular economy results for waste demolition

economy ensures waste is delivered on time and to its intended location, avoiding its complete disposal in landfills. Demolition practices are closely monitored to prevent any negative environmental impacts. From the green demolition framework based on BIM and JIT delivery towards a circular economy (Fig. 9), it can be explained that demolition planning; 1) starts from the use of BIM for 3D BIM modeling and QTO process 2), with the addition of 3R waste management planning 3). The 3D BIM model is integrated into 4D BIM modeling 4) for demolition sequence planning. The QTO results serve as data for calculating factored waste volume, the number of trucks, and planning the destination location for waste delivery 5). At the same time, the reverse 4D BIM demolition scheduling is integrated as data for determining the start and finish dates of one JIT delivery cycle 6). The destination for demolition waste delivery is added 7) according to the

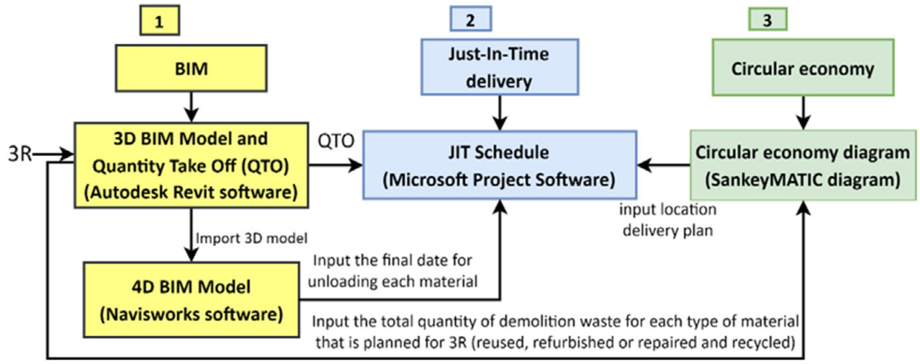


Fig. 8: Integration of BIM, JIT delivery, and circular economy concepts in the planning of building demolition

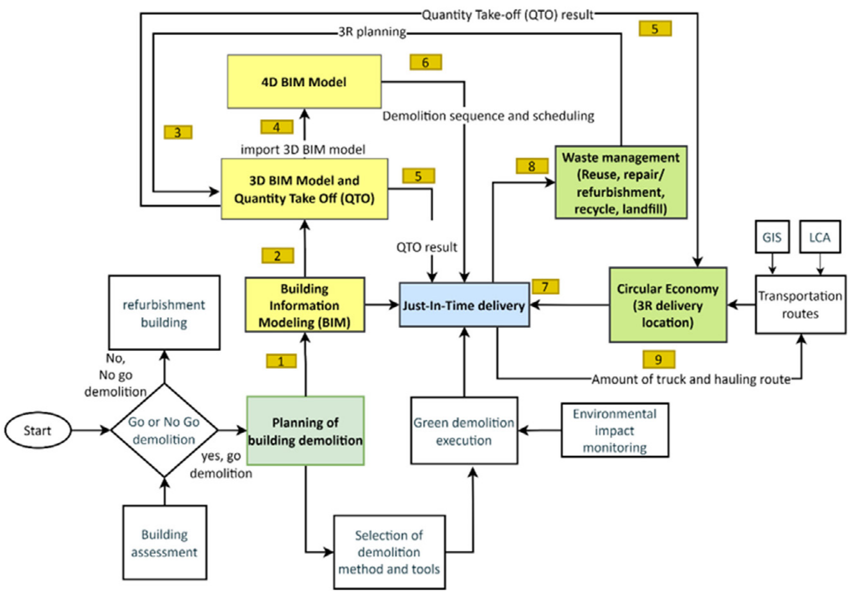


Fig. 9: A green demolition framework based on BIM and JIT delivery towards a circular economy

3R classification plan and waste management 8) so that the total number of hauling routes and transport equipment can be planned and arranged to be more effective and efficient 9). The parameters developed in demolition planning include BIM, JIT delivery, and the circular economy is employed to automate waste estimation via QTO, classify potential waste based on the 3R principle (reduce, reuse, recycle), organize the demolition process sequence, and develop schedules. JIT delivery parameter focuses on managing and scheduling the delivery of demolition waste. The circular economy parameter involves planning waste management, setting delivery goals, determining transportation quantities, and aligning with circular economic principles. Research that develops a framework using BIM features for building waste demolition, both conceptually and in case studies, requires further improvements. Andriyani *et al.* (2023) proposed a demolition process framework that lacks the inclusion of identifying probable 3R demolition debris. In order to ensure a comprehensive methodology, it is crucial to incorporate a circular economy approach into demolition planning. It is worth mentioning that this approach has not been examined in a case study as of yet. Kim *et al.* (2017) created a method for assessing the amount and variety of demolition waste by utilizing Archicad as a BIM tool. The system must integrate 3R waste management strategies or address managerial elements beyond just automated volume calculations with BIM.

CONCLUSION

The study proposes a novel framework for planning demolitions that also develops a green demolition framework based on BIM and JIT delivery, focused on the circular economy concept in the urban area. This study delves into the utilization of BIM, JIT delivery, and the circular economy principle in a specific scenario where digital technology is employed to strategize the demolition of tall structures. The exploration establishes a framework for the demolition process to be green, efficient, effective, and sustainable. At the core of this strategy lies the integration of BIM technology to streamline waste management approaches by automating waste estimation and inventory for 3R projects within a 3D BIM model. This innovation leverages Autodesk Revit's scheduling and material take-off capabilities to accurately quantify resources. The study explores the advanced application of BIM to visually simulate demolition sequence in a top-down approach within a Reverse 4D BIM model. The demolition sequence is accomplished using the time liner feature in Navisworks, where 3D models are integrated, and real-time demolition timelines can be adjusted to reflect its actual progress. The 4D BIM model allows for customization of the demolition sequence visualization, taking into account the planned demolition schedule and estimated duration for each building element as specified in the 3D BIM model. In the given case study, the demolition of a 6-story building is projected to take 88 days, with work being carried out on all seven days of the week. The process begins by removing architectural elements from level 5 down to level 0, following this sequence: windows (4 days), doors (4 days), railings (3 days), and ceramic floors (8 days). Subsequently, the structural elements are dismantled in the following order: structure floors, walls, beams, stairs, and columns, spanning 11 days from level 6 to level 0, consistent with the 3D modeling. The waste estimation through QTO results produces 160 m^3 of reusable waste (windows, doors, and steel railings), 8 $m^3$of repairable and refurbishable waste, and 3,972 m^3 of recyclable waste (concrete, brick wall, steel reinforcement, aluminum door, partition wall, and PVC door). The green demolition framework minimizes environmental impacts through selective demolition, enhances waste management via 3R, and is an effective mitigation and evaluation tool for eco-friendly project management. The innovative framework focuses on preserving structures during demolition to minimize pollution and optimize waste management efficiency. Microsoft Project was employed to develop a JIT delivery schedule that included reverse 4D BIM data, truck quantity data, and various destination locations. The integration of reverse 4D BIM with JIT delivery scheduling ensures a comprehensive cycle of demolition activities. This approach enables the entire process, from waste collection to economy circular drop-off location, to be completed within 1-2 days, beginning collection when demolition has reached 50% completion and increasing haulage vehicle availability. The planned delivery destinations for types of waste that are reused, repaired, and renewed in the case study include 132 m^3 to second-hand shops, 31 m^3 to consumer wood and 1038 m^3 to other construction projects around the demolition site, while for waste recycling, delivery destinations include recycling facilitators 38 m^3, brick factories 2,000 m^3, steel factories 35 m^3, concrete factories 918 m^3; and the rest goes to landfill. The results confirm the effectiveness of the green demolition framework as a tool for project management, enabling better planning of project duration and optimization of transportation resources. This research aspires to set a precedent for more sustainable and environmentally friendly demolition practices contributing to a circular economy. The waste management innovation provided includes notable advancements and carefully planned demolition sequencing that integrates the potential for 3R waste, efficient transportation of resources, and reduced environmental impact by utilizing both BIM and JIT delivery methods. The government should consider the green demolition framework when developing and refining demolition regulations, including information and communication technology (ICT) and circular economy concepts. It is imperative for the government to establish strict enforcement regulations mandating contractors or owners to adopt the proposed model during the demolition permit process. Additionally, a significant obstacle lies in coordinating efforts among stakeholders. Efficient coordination and communication among all involved parties are essential for executing BIM-enabled demolition planning procedures, emphasizing material recovery and reuse. This study needs to account for the selection of demolition methods, stake holder coordination and their environmental impacts in the planning. Future studies can further develop the green demolition framework by emphasizing the importance of eco-friendly demolition method planning and establishing a system for sharing information to ensure efficient and coordinated demolition processes.

AUTHOR CONTRIBUTIONS

N. Andriyani, performed the literature review, experimental and exploring work, drafted the manuscript; T.J.W. Adi supervised all experiments and manuscript preparation and checked the analysis result; Suprobo supervised all experiments and manuscript preparation; Aspar, W.A.N. supervised manuscript drafting; A.D. Jatmiko contributed in exploring work, interpretation result and preparing the manuscript; A.D. Santoso contributed in manuscript drafting, critical revisions, and graphically abstract. Generally, all authors of the current manuscript are main contributors and have an equal primary role in conducting research according to their fields of expertise and publishing this article in highly reputable and globally indexed journals.

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CONFLICT OF INTEREST

The authors declare that there are no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, were observed by the authors.

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ABBREVIATIONS

%	Percent
BIM	Building information modeling
3D	3-Dimensional
4D	4-Dimensional
CDW	Construction and demolition waste
CE	circular economy
DKI	Daerah khusus ibukota (special capital region)
F_{wvc}	Waste volume factor exchange
ICT	Information and communication technology
JIT delivery	Just-In-Time delivery
m^2	Meter square
m^3	Cubic meter
m	Meter
N_{truck}	Number of trucks
PVC	Polyvinyl chloride
Reverse 4D BIM	Reverse four-dimensional building information modeling

R-based framework	3R-principle to 10R (reduce, refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover)
RFID	Radio frequency Identification
3R-principle	Reduce, reuse, and recycle
3R	Reuse, repair or refurbish, and recycling
10R	Refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover
QTO	Quantity take-off
$V_{QTO\ BIM}$	QTO BIM volume
V_f	Factored demolition waste volume
V_{truck}	Truck volume
WtE	Waste-to-energy

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