Joint CSCE Construction Specialty & CRC Conference 2025
Conférence conjointe spécialisée en construction de la SCGC et CRC-2025

Montreal, Quebec
July 28-31, 2025 / *28-31 juillet 2025*

FASTQTO FOR CIRCULAR CONSTRUCTION: A DATABASE-DRIVEN FRAMEWORK FOR RAPID QUANTITY TAKEOFF FOR END-OF-LIFE DECISION-MAKING

R. Orenga Panizza[1]*, S.K. Vakkanthula[1], A. Mollaei[2] and M. Nik-Bakht[1]

[1] Dept of Building, Civil & Environmental Engineering, Concordia University, Montréal, QC, Canada
[2] Adaptis, Suite 200 – 155 Queens Quay E, M5V 0W4, Toronto, Ontario, Canada

ABSTRACT: Proper decision-making at the end-of-life (EoL) of a built facility is critical for addressing the circularity gap in the construction industry. The reusability of components and materials in new projects is highly dependent on their careful extraction from existing building stocks reaching their EoL. To prepare for such recovery, buildings must be assessed for their recovery potential, which heavily relies on detailed information about their material composition. These assessments are crucial for planning viable deconstruction projects that minimize adverse impacts while ensuring profitability. In practice, however, many (if not most) EoL buildings lack such documentation, making the building's recovery assessment extremely challenging. This study proposes the fastQTO (fast quantity takeoff) framework, a database-driven methodology that enables QTO estimation based only on high-level building attributes. The framework leverages historical construction data, material selection rules, and standardized design requirements to estimate material quantities of industrial building envelopes. The methodology involves the development of a structured SQL database that aggregates construction knowledge and predefined material dependencies. The approach was validated through two industrial building case studies, demonstrating promising accuracies when compared to other QTO methods from the literature. The fastQTO framework offers a streamlined approach to early-stage material estimation, significantly reducing the time and information required for QTO. Future developments will focus on automating the process, expanding the material database, and refining assumptions for additional building typologies. These advancements will enhance the framework's applicability in circular construction strategies and EoL decision-making.

1. INTRODUCTION

The construction industry is one of the largest consumers of raw materials and producers of waste worldwide (Carra & Nitesh, 2017; Giljum et al., 2014). In North America, approximately 40% of raw materials consumed are construction materials (CCME, 2019) and the U.S. alone produces over 600 million tons of construction-related waste (Sustainable Management of Construction and Demolition Materials, n.d.). This predominantly linear model of resource consumption poses significant environmental challenges, emphasizing the need for a transition to more circular practices (Lemmens & Luebkeman, 2016). Circularity in construction follows the 9R framework, which prioritizes strategies such as refusing, rethinking, reducing, repairing, reusing, refurbishing, remanufacturing, repurposing, recycling, and recovering materials (Kirchherr et al., 2017; Potting et al., 2017; van Buren et al., 2016).

At the end-of-life (EoL) stage of buildings, decisions regarding material and component recovery play a crucial role in closing the circularity gap. Beyond determining a building's final fate, these decisions also

affect the availability and quality of reclaimed materials for future construction. For instance, the choice between demolition and deconstruction significantly affects the condition and reusability of extracted materials. Maximizing reuse potential requires precise extraction methods, which, in turn, depend on accurate assessments of a building's material composition. However, a significant challenge in this process is the lack of detailed documentation for many existing buildings. Without comprehensive records, estimating material quantities and assessing recovery potential become complex and uncertain.

Current methods for quantity takeoff (QTO) and material inventorying often rely on extensive data, limiting their applicability to buildings with incomplete or missing information. Existing approaches—such as parametric analysis, BIM, and machine learning—have made progress in material estimation; however, each presents its own challenges. Parametric analysis often lacks validation and overlooks variability within building types (Gontia et al., 2018; Lanau & Liu, 2020), while BIM methods, though validated, show significant accuracy fluctuations and require substantial resources (Çetin et al., 2022; Negendahl et al., 2022; Volk et al., 2018). Machine learning models depend on large datasets and suffer from inconsistent accuracy metrics across studies (Akanbi et al., 2020; Cha et al., 2020; Kobylinska et al., 2023; Soultanidis & Voudrias, 2023). These limitations hinder the scalability of current approaches. To address this gap, this study aims to develop a framework for QTO assessment tailored to buildings with limited documentation. By exploring an alternative estimation method and its accuracy despite data constraints, this research seeks to support more effective decision-making for material recovery and circular construction practices.

2. METHODOLOGY

The framework for fast QTO assessment presented in this study was developed with the help of a two-phase hybrid methodology, as illustrated in Figure 1. The first phase follows a top-down approach, analyzing of the North American industrial building stock to characterize construction methods in existing buildings. The second phase adopts a bottom-up approach, examining the individual assemblies that constitute these buildings to provide a more detailed understanding of their composition. By integrating these two approaches, a comprehensive database is created, forming the foundation for the fastQTO framework for industrial buildings in North America.

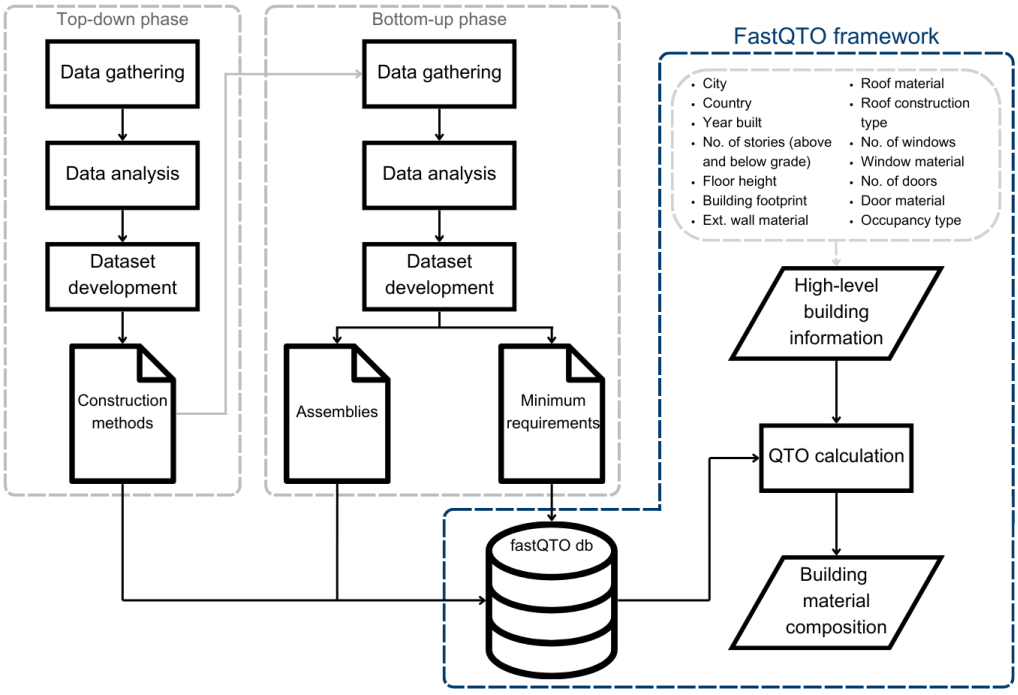

Figure 1: Framework development

2.1 Top-Down Analysis of North American Industrial Buildings

Buildings can be constructed using various materials and technologies for their structural, partitioning, and finishing elements. However, each historical period is characterized by distinct construction styles shaped by architectural trends and technological advancements, which influence the materials and design approaches commonly used (Miatto et al., 2019). A three-step methodology was employed to capture these trends.

First, a data collection phase involved gathering historical building codes, construction history documents, heritage building reports, peer-reviewed publications, and architectural literature to compile relevant information on industrial building construction. This was followed by a data analysis phase, where the collected information was systematically examined to identify construction methods used in industrial buildings over time. The focus was on historical and contemporary construction practices, particularly the commonly used materials in critical elements of the building envelope, as construction methods play a key role in determining material composition (Akanbi et al., 2020; Cha et al., 2017, 2020). Lastly, a construction method dataset was developed, cataloging construction methods along with their corresponding periods of adoption or discontinuation. This structured top-down approach ensures a comprehensive understanding of the evolution of construction methods in industrial buildings and is the first layer of data to be included into the database.

2.2 Bottom-Up Analysis of Industrial Building Assemblies

After establishing the construction methods used in industrial buildings, a detailed bottom-up analysis was conducted to define the composition of envelope assemblies commonly found in these buildings. Similar to the top-down phase, this analysis follows a three-step methodology to identify the materials used within each assembly type and their minimum design requirements.

The first step, data collection, involved an extensive review of North American building design codes, industry standards, and architectural sources. The data analysis phase then examined this information to extract envelope assemblies that align with the previously identified construction types, as well as the minimum design requirements for different assemblies and periods. Finally, the dataset development phase resulted in two integrated datasets: one cataloging the different assembly types across the building envelope and another detailing the minimum requirements associated with these assemblies over time. This bottom-up approach provides a refined dataset that complements the construction method dataset, ensuring a more granular understanding of industrial building components.

2.3 FastQTO Estimation Framework Development

With all the collected data—encompassing construction methods, assembly types, and minimum design requirements—the database to assist the fast QTO framework can be developed using structured database design principles. This structured database serves as the core of the framework, allowing for fast estimation of building composition based on key high-level building attributes (as shown in Figure 1). Thus, some steps are followed for designing this database. First, a requirement analysis is performed to identify the purpose of the database, understand data type, as well as define key relationships. Then, the conceptual design of the database will be developed to represent data entities, attributes, and relationships. This is followed by the physical design and implementation of the tables within Microsoft SQL Server Management Studio (SSMS) (SQL Server Management Studio (SSMS), n.d.).

3. FRAMEWORK DEVELOPMENT

This section presents the findings of the study following the structure of the proposed methodology. First, the characterization of North American industrial building construction is outlined, highlighting historical trends in construction methods and material use. Next, the composition of industrial building assemblies is

detailed, providing insights into the materials and configurations of different envelope assemblies. Finally, the development of the Fast QTO database is then described, summarizing how construction methods, assembly types, and minimum design requirements were integrated into a structured dataset.

3.1 Characterization of North American Industrial Building Construction

Industrial building construction evolved significantly from the pre-1900s to the post-1910s, driven by advancements in materials, structural innovations, and lessons learned from major disasters (Banham, 1986; Sugden, 2017). Before 1900, factories were typically multi-story structures built with thick masonry walls and internal timber framing, known as "regular mill construction." These buildings relied on small, recessed windows, resulting in poor daylighting, and fireproofing was limited to slow-burning timber, which was resistant but not fireproof (Banham, 1986; Wilson, 2010).

The early 1900s saw the adoption of reinforced concrete frames, which gradually started to replace timber and brick construction, though timber and clay brick constructions were still common up until around the 1980s (Davis & Malomo, 2024; Wilson, 2010), especially in places with low risk of earthquakes. This shift was accelerated by the 1902 Pacific Coast Borax fire, which highlighted the superior fire resistance of concrete (Charles, 2015). The 1906 San Francisco earthquake further reinforced the need for stronger, more resilient structures (Banham, 1986; Wilson, 2010). Factories of this period began to feature more open facades with thinner walls and larger windows, improving natural daylighting. Flat roofs also became more common, maximizing interior lighting efficiency (Banham, 1986).

Starting in the post-1910s, steel frames elements became widespread, leading to a fundamental shift in industrial architecture. Multi-story factories were largely replaced by single-story industrial sheds with large-span steel trusses, roof monitors, and clerestory glazing to enhance daylight distribution. Also, in the post-1910s, prefabricated reinforced concrete started to be utilized, but it came to be the obvious and widely selected choice in 1960, when the NRC incorporated it into the National Building Code (National Building Code of Canada 1960, n.d.). Regardless of its form, concrete remained dominant due to its cost efficiency and fire resistance, solidifying its role in modern industrial construction (Charles, 2015).

3.2 Composition of Industrial Building Assemblies

To begin identifying what these building envelopes have been composed of over the years, we need to first categorize them under assemblies and assembly layers. The building envelope is composed of six assemblies: standard wall foundation, basement wall, standard slab on grade, exterior walls, openings, and roof structural frame and deck. The composition layers for each envelope assembly are detailed in Table 1, drawing on the UniFormat classification system (UniFormat™: A Uniform Classification of Construction Systems and Assemblies, 2010).

Table 1: Composition Layers of Building Envelopes

Assembly	Assembly Layers
Standard Wall Foundation	Continuous Footing; Foundation Wall; Reinforcement
Basement Wall	Foundation Wall; Reinforcement; Thermal Insulation; Wall Framing; Wall Interior Skin
Standard Slab on Grade	Thermal Insulation; Floor Slab
Exterior Walls	Exterior Veneer; Exterior Sheathing; Wall Framing; Thermal Insulation; Wall Interior Skin; Masonry Reinforcement (in case of Concrete or Unit masonry construction)
Openings	Door Frame; Door Panel; Window Frame; Window Pane

Roof Structural Frame and Deck	Girders and Beams; Joists; Thermal Insulation; Deck

Material selection in building construction follows a structured approach derived from compliant choices outlined in building code documents. While these materials are compliant options, certain assembly layers allow for variations based on factors such as construction method, building size, and year of construction. Additionally, minimum sizing requirements for various materials also vary based on these factors, ensuring structural adequacy and regulatory compliance. Material selection generally falls under a standardized choice, construction method dependency, historical evolution influence, or building typology influence.

The standard layers of choice are the ones that are generally not subject to variation from building to building and are dictated by standard construction practices. Examples include footings, floor slab, and interior wall skin. Both the footings and floor slab are always constructed using cast-in-place (CIP) concrete, as recommended by code for these foundational elements. Their minimum thickness requirements are also dictated by the building height, floor area, occupancy type and building location. Another example is the interior wall skin for both basement and exterior walls. Gypsum wallboard is the default choice, except when unfinished interiors negate the need for interior wall finishes. The thickness of the board varies based on fire-rating and spacing between the studs that form the wall frame.

Some other materials are selected during the fastQTO process based on dependencies with other structural components, building size or visibly known characteristics, ensuring compliance with construction methods. These happen with foundation and basement walls, exterior wall framing, and roof coverings. The selection between CIP concrete and concrete block for foundation and basement walls depends on the above-grade construction. If the superstructure is masonry, the default choice is that the foundation will be made of concrete block. Minimum wall thickness and depth below grade are determined based on building height, frostline depth, and lateral load conditions. The roof framing material, as mentioned in the previous section, is highly dependent on the building footprint. Thus, if the building span is greater than 23 feet, the roof frame is considered to be structural steel because lumber, as per the building code, cannot accommodate greater spans.

The selection material as accepted by code for exterior wall framing and roof coverings, on the other hand, is based on visible characteristics (exterior wall material and roof material). On the exterior wall framing side, if stucco is used as the exterior finish, the assumption is that the frame will be concrete block, while clay brick siding implies a clay-unit masonry frame. The wall thickness is dictated by the building height and wind load considerations. On the roof covering side, roofing membranes are considered in the framework based on the visual characteristic of the roof. Built-up roofing (BUR) generally requires gravel as ballast, whereas thermoplastic polyolefin (TPO) remains exposed with a reflective finish. Styrene-butadiene-styrene (SBS) has a similar look to asphalt shingles, and ethylene propylene diene terpolymer (EPDM) has matte finish. The thickness depends on building occupancy type.

Other materials are selected for fastQTO process based on their historical influence in construction trends and evolving regulatory frameworks. The main material that is influenced by historical trends is concrete. In addition to masonry exterior walls, exterior walls can be made both by cast-in-place (CIP) concrete or precast concrete. CIP is always considered in exterior walls of buildings constructed before 1960, while precast concrete is considered the norm for structures built after 1960, aligning with advancements in construction methods and regulatory standards (National Building Code of Canada 1960, n.d.). The structural thickness and reinforcement requirements have also changed over time. Finally, given the building type being analyzed, some assembly layers-such as basement wall framing-are not considered at all unless additional information is provided to say otherwise.

3.3 Database Development for fastQTO Framework

To structure the analyzed data within the fastQTO framework while capturing the relationships and dependencies inherent to the QTO process, an SQL database has been designed. This database is built for scalability and future modifications. As outlined in the methodology, it takes high-level building attributes as inputs and, through its structured tables, facilitates the QTO calculations. The database consists of nine

interconnected tables, whose structure and relationships are illustrated in Figure 2. The database includes the *Building_Inputs* table, which stores essential building attributes such as 'year built' and 'exterior wall material.' These attributes are used to determine the construction method, which is retrieved from the *Construction_Methods* table. Once the construction method for the building is identified, materials must be assigned to each assembly layer. These layers, linked to specific assemblies, are defined in the *Envelope_Assemblies* table.

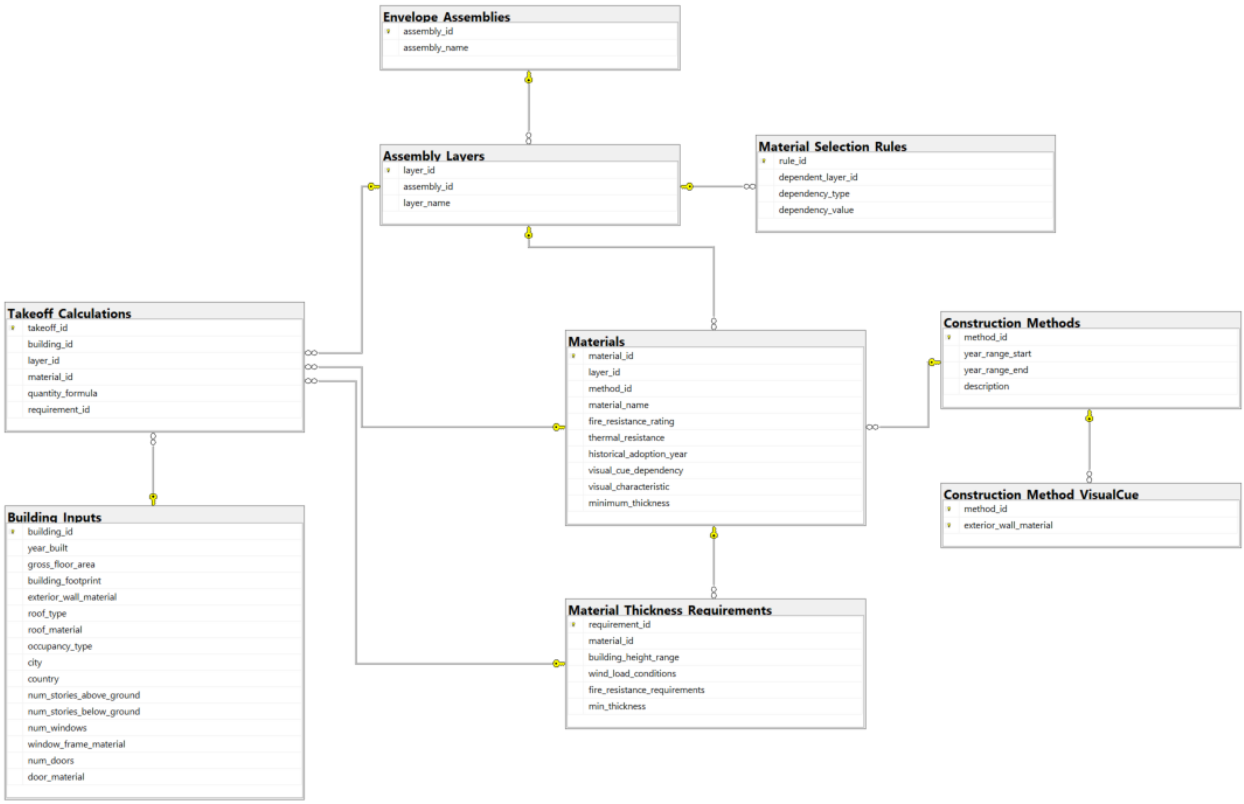

Figure 2: Entity-relationship (ER) diagram for fastQTO database

Material selection is governed by the *Material_Selection_Rules* table, which categorizes dependencies into four types. For layers with a 'Standard' dependency type, the appropriate material is directly mapped from the Materials table without additional conditions. However, for other dependency types— 'method_based,' 'historical,' or 'visual_cue'—the material selection depends on specific constraints. In the case of a 'method_based' dependency, the assigned material is contingent on the construction method recorded for the building. If the dependency type is 'historical,' material selection is based on the year the material was adopted in construction practices. Lastly, for a 'visual_cue' dependency, the material is selected based on observable building attributes, such as architectural features or surface characteristics recorded in the *Building_Inputs* table.

For quantity estimation, each material requires an associated minimum thickness. These values, influenced by parameters such as building height, wind load, and fire resistance standards, are stored in the *Material_Thickness_Requirements* table. The required thickness is retrieved based on key building characteristics, such as the number of stories, and building location. The final occurs in the *Takeoff_Calculations* table, where predefined formulas are stored to compute material quantities. These formulas integrate data from *Building_Inputs* (e.g., gross floor area, footprint, number of stories), material properties (e.g., minimum thickness), and *Assembly_Layers* (e.g., layer type). Each row in the *Takeoff_Calculations* table includes a 'quantity_formula' that is dynamically evaluated using database

inputs to generate final material quantities. This structured approach ensures efficient quantity takeoff estimations within the fastQTO framework.

4. APPLICATION

To evaluate the applicability and accuracy of the developed framework, two case studies are being assessed, comparing the fast QTO framework against the traditional QTO method. This comparison aims to validate the framework's reliability and effectiveness in estimating building quantities while demonstrating its ability to generate results without requiring detailed building data, such as structural and architectural drawings.

4.1 Case Study Definition

To validate the developed fast QTO framework, two case studies have been selected, representing different industrial building typologies from distinct historical periods and construction methods. The first case study is a masonry building constructed in 1936, originally used as an industrial refinery and warehouse, now repurposed as a commercial entertainment facility in Toronto, Canada. The second case study is a tilt-up concrete wall panel warehouse built in 1969, which remains in use as a distribution warehouse in Renton, Washington, USA. These buildings differ in structural systems, roof construction, and material composition, providing a diverse basis for testing the framework's applicability. The necessary building information and drawings for both case studies have been provided by our industry partner. Table 2 summarizes the case study details.

Table 2: Case study details

Description	Case Study #1	Case Study #2
Location	Toronto, ON, Canada	Seattle, WA, USA
Year built	1936	1969
No. of stories	2	1
Building height	8.84 m	5.79 m
Building footprint	919.33 m^2	1858.06 m^2
Gross floor area	2122.46 m^2	1858.06 m^2
Construction type	Masonry Building (Red Bricks)	Tilt-up Concrete Wall Panels
Roof construction	Steel Beams with wooden roof decking	Glulam Beams with wooden roof decking
Original classification	Industrial Building (Refinery & Warehouse)	Distribution Warehouse
Present use	Commercial Use (Entertainment facility)	Distribution Warehouse

To analyze the framework's application, the first step involved estimating the material quantities of the building envelope assemblies using traditional QTO methods. This process relied on available construction drawings and as-built documentation that specify the layers and materials used in the envelope. The dimensions of these assemblies and components were extracted to estimate quantities. However, given the often-limited level of detail in historical drawings, certain secondary components—such as exterior thermal insulation, blocking, bracing, or architectural elements—were not included in the estimates.

Although the building owners had access to the original drawings, the documentation had limitations due to the age of the buildings. While the drawings provided details on envelope elements and recorded various modifications and renovations over time, they were incomplete in several aspects. For instance, footing dimensions and the foundation wall depth below the basement were missing, making estimation infeasible under traditional QTO methods, and were therefore excluded from the analysis. In case study #1, the presence of roof sheathing was confirmed, but its material and thickness were unspecified, and no details

were provided regarding the flat roof covering. Additionally, while the drawings indicated the height and length of window walls, they lacked specifications for mullions, transoms, and materials. These gaps were filled using typical industry standards and dimensions. Similarly, in case study #2, the drawings omitted reinforcement details for the tilt-up concrete exterior walls and external wall openings, affecting envelope quantity estimates. The office space within this building, measuring 743.24 m², has wood-framed walls, but the drawings did not specify stud size or spacing. To address this, specifications from Section 2507(b) of the 1967 UBC—applicable to two- and three-story structures with floor heights of 10 feet or less—were adopted, as the 9'8" interior height met these criteria.

4.2 Testing & Validation

The results from the case study demonstrate the usability of the proposed framework in generating fast QTO estimates. By inputting high-level building attributes, with the help of the database the appropriate construction methods, corresponding assemblies, and assembly layers, as well as their materials based on predefined rules were identified. This structured data enhances efficiency by reducing complexity and therefore making it possible for QTO to be performed with minimal building information. The primary discussion point, however, concerns the accuracy of fastQTO compared to traditional QTO (Figure 3).

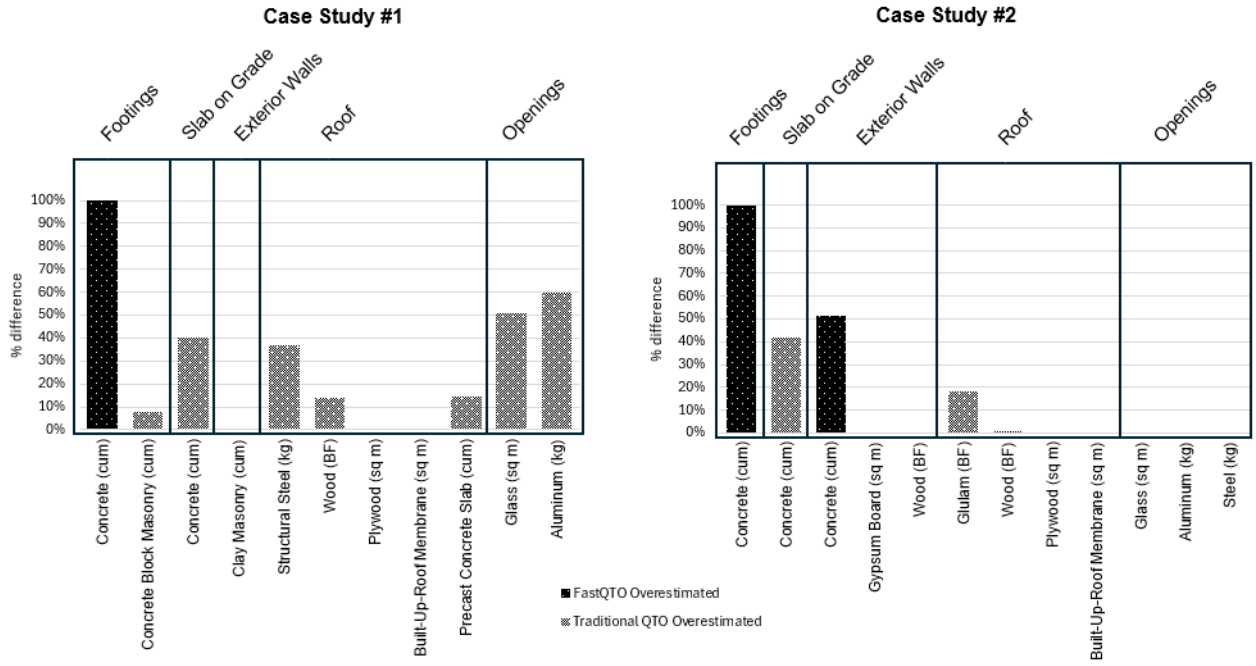

Figure 3: Accuracy gap between QTO approaches

Concrete quantities varied significantly between fastQTO and traditional QTO due to differences in design details and code assumptions. The largest discrepancy was observed in the footings, where fastQTO significantly overestimated concrete quantities. This occurred because the case study drawings lacked footing details, resulting in a zero quantity in traditional QTO. In contrast, fastQTO applied minimum footing dimensions based on building code requirements, leading to a nonzero quantity and a 100% difference. Similarly, slab-on-grade quantities were underestimated because the building code specifies a minimum thickness of 3.5 inches (89mm), while actual construction practices typically use 5 inches (127mm) or more, particularly in industrial buildings where increased loads require thicker slabs. For tilt-up concrete walls, fastQTO closely matched the drawing-specified thickness of 150mm but slightly overestimated the required quantity due to an additional building code constraint that mandates a minimum thickness of 1/25 of the support spacing.

FastQTO demonstrated good accuracy for exterior wall and roof assemblies due to their relatively simple material compositions. In case study 1, exterior walls were primarily brick, while in case study 2, they were concrete, both of which are monolithic materials. The only variable affecting accuracy was the thickness, which fastQTO determined based on minimum building code requirements. For sheathing materials (roof and walls), fastQTO accurately predicted surface areas since these calculations are independent of building codes and rely on openings. However, the challenge lies in determining material thickness, which requires further historical code analysis to establish period-specific material standards. The greater issue found in the roof assembly was that FastQTO significantly underestimated structural steel quantities, particularly for case study 1. Similarly to tilt-up concrete walls and slab on grade, this discrepancy is attributed to limitations in historical building codes—building code specifies a beam thickness that is not consistent with the case, therefore underestimating the quantity of steel in case study #1.

FastQTO effectively captures wood components, as span tables allow material quantities to be predicted based on lengths for various load cases. This capability can be extended to engineered lumber (e.g., Glulam, LVL) using industry publications. Additionally, fastQTO can account for renovations and additions if additional information on the modified assemblies is available in addition to the high-level building inputs already required, as it enables applying the code-in-force during the renovation period. The framework also performs well for monolithic masonry construction, particularly unit masonry (clay and concrete), and accurately predicts sheathing material areas. However, some limitations remain. Concrete estimation is challenging, as the code specifies only minimum thicknesses, which are dependent on loads rather than dimensions, often leading to underestimations. Additionally, roof lumber elements, such as joists and rafters, may still require additional information and processing, particularly for complex roof geometries.

5. CONCLUSION

This study developed and evaluated the fastQTO framework, a structured methodology for rapid QTO estimation based only on high-level building attributes. The application of the framework through two case studies demonstrated that the framework effectively estimates material quantities for industrial building envelopes, with results showing good consistency with traditional QTO methods for most assemblies. However, variations were observed in elements with load-dependent thickness requirements, particularly in foundation components, where limited design details led to discrepancies.

The primary contributions of this research lie in the development of a structured SQL database that aggregates historical construction knowledge and material selection rules. By integrating standardized construction methods, material dependencies, and minimum design requirements, the framework minimizes the need for detailed architectural and structural drawings while significantly reducing estimation time. This systematic approach facilitates the assessment of material recovery potential in circular construction strategies.

Despite its advantages, the fastQTO framework has limitations. The estimation process relies on predefined assumptions regarding material composition, particularly for hidden layers, where historical data may not always capture material transitions accurately. Additionally, the framework currently focuses on major envelope assemblies and does not explicitly account for interior finishes. The accuracy of quantity estimations depends on the completeness of the material database, requiring careful calibration of material selection rules to align with actual industry practices. Lastly, the evaluation of the framework's accuracy is based on only two case studies, which limits its generalizability. A broader set of case studies is needed to better capture the variability within the existing industrial building stock.

Future work should focus on automating the QTO process by integrating the framework into a computational model, enabling seamless data input and real-time material estimation. Expanding the material database to include a broader range of building typologies, refining typical thicknesses for finishes such as exterior walls and floors, as well as allow for additional design inputs when available would enhance accuracy and increase the potential for integration with existing tools. Additionally, further research is needed to establish slope factors for sloped roofs and refine assumptions for load-bearing components. Incorporating additional case studies for validation will also be essential to assess and improve the framework's generalizability.

These advancements will improve the framework's adaptability, making it a more robust tool for material quantification in diverse construction contexts.

REFERENCES

Akanbi, L. A., Oyedele, A. O., Oyedele, L. O., & Salami, R. O. (2020). Deep learning model for Demolition Waste Prediction in a circular economy. *Journal of Cleaner Production*, *274*. https://doi.org/10.1016/j.jclepro.2020.122843

Banham, R. (1986). *A Concrete Atlantis, US Industrial Building and European Modern Architecture 1900-1925*. The MIT Press.

Carra, G., & Nitesh, M. (2017). Circular Business Models for the Built Environment. *Arup, BAM & CE100*, 1–25. http://www.duurzaam-ondernemen.nl/circular-business-models-for-the-built-environment-research-report-by-arup-bam/

CCME. (2019). *Guide for identifying, evaluating and selecting policies for influencing construction, renovation and demolition waste management*.

Çetin, S., Gruis, V., & Straub, A. (2022). Digitalization for a circular economy in the building industry: Multiple-case study of Dutch social housing organizations. *Resources, Conservation & Recycling Advances*, *15*, 200110. https://doi.org/10.1016/j.rcradv.2022.200110

Cha, G. W., Kim, Y. C., Moon, H. J., & Hong, W. H. (2017). New approach for forecasting demolition waste generation using chi-squared automatic interaction detection (CHAID) method. *Journal of Cleaner Production*, *168*, 375–385. https://doi.org/10.1016/j.jclepro.2017.09.025

Cha, G. W., Moon, H. J., Kim, Y. M., Hong, W. H., Hwang, J. H., Park, W. J., & Kim, Y. C. (2020). Development of a prediction model for demolition waste generation using a random forest algorithm based on small datasets. *International Journal of Environmental Research and Public Health*, *17*(19), 1–15. https://doi.org/10.3390/ijerph17196997

Charles, J. M. (2015). *Shaping Time in the City: A Cultural History of Concrete Modernity in Montreal, 1903-2015*. McGill University.

Davis, L., & Malomo, D. (2024). *Geometrical and Material Characterization of Old Industrial Masonry Buildings in Eastern Canada*. 351–364. https://doi.org/10.1007/978-3-031-61539-9_28

Giljum, S., Dittrich, M., Lieber, M., & Lutter, S. (2014). Global patterns of material flows and their socio-economic and environmental implications: A MFA study on all Countries world-wide from 1980 to 2009. *Resources*, *3*(1), 319–339. https://doi.org/10.3390/resources3010319

Gontia, P., Nägeli, C., Rosado, L., Kalmykova, Y., & Österbring, M. (2018). Material-intensity database of residential buildings: A case-study of Sweden in the international context. *Resources, Conservation and Recycling*, *130*(June 2017), 228–239. https://doi.org/10.1016/j.resconrec.2017.11.022

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Kobylinska, N. E., Raghu, D., Gordon, M., Hunhevicz, J., & De Wolf, C. (2023). Predicting Recoverable Material Stock in Buildings: Using Machine Learning With Pre-Demolition Audit Data As a Case Study. *Proceedings of the European Conference on Computing in Construction*. https://doi.org/10.35490/EC3.2023.184

Lanau, M., & Liu, G. (2020). Developing an Urban Resource Cadaster for Circular Economy: A Case of Odense, Denmark. *Environmental Science and Technology*, *54*(7), 4675–4685. https://doi.org/10.1021/acs.est.9b07749

Lemmens, C., & Luebkeman, C. (2016). *The Circular Economy in the Built Environment*. https://www.arup.com/globalassets/downloads/insights/cirular-economy-in-the-built-environment.pdf

Miatto, A., Schandl, H., Forlin, L., Ronzani, F., Borin, P., Giordano, A., & Tanikawa, H. (2019). A spatial analysis of material stock accumulation and demolition waste potential of buildings: A case study of Padua. *Resources, Conservation and Recycling*, *142*, 245–256. https://doi.org/10.1016/j.resconrec.2018.12.011

National Building Code of Canada 1960. (n.d.). https://doi.org/https://doi.org/10.4224/40001400

Negendahl, K., Barholm-Hansen, A., & Andersen, R. (2022). Parametric Stock Flow Modelling of Historical Building Typologies. *Buildings*, *12*(9). https://doi.org/10.3390/buildings12091423

Potting, J., Hekkert, M., Worrell, E., & Hanemaaijer, A. (2017). Circular Economy: Measuring innovation in

the product chain - Policy report. *PBL Publishers*, *January*.
Soultanidis, V., & Voudrias, E. A. (2023). Modelling of demolition waste generation: Application to Greek residential buildings. *Waste Management & Research: The Journal for a Sustainable Circular Economy*, *41*(9), 1469–1479. https://doi.org/10.1177/0734242X231155818
SQL Server Management Studio (SSMS). (n.d.). https://learn.microsoft.com/en-us/ssms/sql-server-management-studio-ssms
Sugden, E. (2017). *The Adaptive Reuse of Industrial Heritage Buildings: A Multiple-Case Studies Approach*. 140. http://hdl.handle.net/10012/12823
Sustainable Management of Construction and Demolition Materials. (n.d.). U.S. EPA. Retrieved February 19, 2025, from https://www.epa.gov/smm/sustainable-management-construction-and-demolition-materials
UniFormat™: A Uniform Classification of Construction Systems and Assemblies. (2010). Construction Specifications Institute.
van Buren, N., Demmers, M., van der Heijden, R., & Witlox, F. (2016). Towards a circular economy: The role of Dutch logistics industries and governments. *Sustainability (Switzerland)*, *8*(7), 1–17. https://doi.org/10.3390/su8070647
Volk, R., Luu, T. H., Mueller-Roemer, J. S., Sevilmis, N., & Schultmann, F. (2018). Deconstruction project planning of existing buildings based on automated acquisition and reconstruction of building information. *Automation in Construction*, *91*(July 2017), 226–245. https://doi.org/10.1016/j.autcon.2018.03.017
Wilson, C. A. (2010). *Adaptive Reuse of Industrial Buildings in Toronto , Ontario*. *January*, 77.