Promoting Circular Economy in the Construction Industry within the APEC Region Using an Industrial Symbiosis Approach

APEC Policy Partnership for Science, Technology and Innovation

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Produced by

Author:

Ts. Dr. Syed Ahmad Farhan bin Syed Ahmad Iskandar
Independent Research Contractor
Skudai, Johor,
Malaysia.

Reviewer:

Prof. Dr. Nasir Shafiq
Project Overseer
Universiti Teknologi PETRONAS
Seri Iskandar, Perak,
Malaysia.

For
Asia-Pacific Economic Cooperation Secretariat
35 Heng Mui Keng Terrace
Singapore 119616
Tel: (65) 68919 600
Fax: (65) 68919 690
Email: info@apec.org
Website: www.apec.org

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Executive Summary

The construction industry is the single-largest global consumer of resources, contributing 63% of the global material consumption. Furthermore, the demand for resources to manufacture construction materials could escalate in the future to support growths in urbanization and urban redevelopment, giving rise to pressing concerns with regard to resource depletion. Moreover, the low efficiency in resource utilization in the construction industry leads to the high rate of construction and demolition waste (CDW) generation. The CDW contributes to more than a third of the global waste generation hence raises concerns with regard to waste disposal. Indeed, the concerns associated with resource depletion and waste disposal stem from the take-make-dispose-waste approach of the linear economy that is ingrained in the construction industry. Duly, the concept of a circular economy has emerged as the solution that addresses all drawbacks of the linear economy. Asia-Pacific Economic Cooperation (APEC) can play a key role in the transition to a circular economy at global, regional and local scales. APEC economies contributed about 43% of the global solid waste in 2016, where 59% of the waste was mismanaged. In order to concurrently address the concerns with regard to the high solid waste generation rate, inclusive of that of CDW, as well as the high resource consumption rate of the construction industry, a transition to a circular economy has to be promoted. A project has been initiated under APEC Policy Partnership on Science, Technology and Innovation (PPSTI) to develop a conceptual framework for promoting circular economy in the construction industry within the APEC region using an industrial symbiosis approach. Data on solid waste management in selected APEC economies were obtained. Amounts of annual generation range from 7.39 to 75.80Mt. Values of daily generation per capita range from 0.53 to 8.06kg/capita/day. Recycling rates range from 15 to 75%. The industrial symbiosis approach presents an opportunity to maximize the recycling rates as a result of adopting a circular economy. Perspectives of construction industry stakeholders from the economies were gathered by means of a questionnaire survey on aspects pertaining to the valorization of solid waste for the manufacture of construction materials and adoption of circular economy in the construction industry within the economies. Responses of the stakeholders reveal that a wide range of waste types has the potential to be valorized to manufacture a wide range of construction materials at substantial amounts. Implementation of efforts to adopt circular economy has started in most construction industry organizations, although the levels of implementation are mostly elementary. The responses also reveal the importance of considering several aspects with regard to manufacture and recovery of construction materials in adopting the circular economy and addressing several challenges that could hinder the adoption. The conceptual framework is developed, where solid waste generated from agricultural and manufacturing industries as well as municipal and industrial sources of consumption, along with CDW, are to be utilized as feedstock for the manufacture of construction materials as well as other construction industry operations. An industrial symbiosis network of organizations from the industries is to be established. The draft framework was presented at a workshop to gather perspectives from circular economy and construction industry experts and stakeholders to enhance the maturity of the framework. Further enquiries were made to the experts and stakeholders during post-workshop discussions to prior to finalizing the framework. Recommendations have been made for implementation of the framework.

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Background

The construction industry has been considered as a prime mover of economic development. It substantially contributes to generating employment opportunities, investments and revenue, hence supporting gross domestic product (GDP). In tandem with economic development, the construction industry has a profound impact on social development. It provides access to comfort, connectivity, education, entertainment and necessities.

However, in spite of the positive economic and social impacts of the construction industry, its adverse environmental impact has to be contemplated. Indeed, the construction industry is the single-largest global consumer of resources, as highlighted by the World Economic Forum (2017). It consumes energy, land, materials and water at high rates. The resources are utilized, not only during construction, but also during occupation for maintenance and refurbishment. The Organization for Economic Co-operation and Development (2019) estimated that the construction industry contributes 50% of the global resource consumption. If materials are solely considered, according to Global Infrastructure Hub (2021), the industry contributes 63%.

The resource consumption could increase at higher rates in the future as demand increases. According to the United Nations (2019), the global population is projected to increase to 8.55 billion by 2030, which is a 60% increase relative to that of 5.33 billion in 1990. About 60% of the global population is projected to reside in urban areas by 2030, indicating a noteworthy increase relative to that of about 43% in 1990.

Hence, the demand for resources to manufacture construction materials could escalate to support growths in urbanization and urban redevelopment, which gives rise to pressing concerns with regard to resource depletion.

The high consumption rate is attributed to, not only the high demand for resources, but also the low efficiency in resource utilization. The low efficiency entails that the high consumption rate is coupled with a high waste generation rate. The waste is generated during processing of raw materials to manufacture construction materials as well as during construction and demolition. In general, the waste materials are predominantly brick, concrete and mortar, followed by, but not limited to, glass, metals, plastic and wood. Holland Circular Hotspot (2022) estimated that construction and demolition waste (CDW) contributes to more than a third of the global waste generation. In addition, Wang *et al.* (2019) estimated that the rate of global CDW generation is over 10 billion tonnes per year. The high rate of CDW generation, as well as the resource depletion, are pressing intergenerational and intergovernmental concerns. On the whole, waste disposal leads to dependence towards landfills, atmospheric pollution resulting from waste incineration, as well as health and safety hazards that arise from illegal dumping.

Linear Economy in the Construction Industry

Indeed, the concerns associated with resource depletion and waste disposal stem from the take-make-use-dispose-waste approach of the linear economy that is ingrained in the construction industry. Conventionally, construction materials are designed, manufactured and assembled for one-time use. At the end of life, the materials are disposed of without considering the potential for recovery.

Recovery of Construction and Demolition Waste (CDW)

Certainly, recovery of CDW is necessary, although the adoption at present is inadequate. Other than reducing the adverse effects associated with waste disposal, CDW recovery reduces the dependence towards natural resources and hence counteracts the potentially escalating demand for the resources in the future. However, according to Galvez-Martos and Istrate (2020), only 20–30% of CDW in selected emerging economies is recovered in spite of implementing waste recovery methods, owing to inefficient planning and management. On another note, about 80% of CDW are inert composites, such as brick, concrete and mortar, where recovery of the composites poses concerns with regard to not only quality, but also perceived quality, which customarily leads to low recovery values (Li *et al.*, 2023). Hence, CDW recovery has to be planned and managed efficiently in order to maximize recovery values and rates, which could be difficult to realize owing to complications and limitations with regard to the implementation of a recycling economy.

Concept of a Circular Economy

The concept of a circular economy has emerged as the solution that addresses all drawbacks of the linear economy. According to the Ellen MacArthur Foundation (EMF) (n.d.-a), a circular economy is an economy that is restorative and regenerative by design. The main principles of a circular economy are elimination of waste and pollution, circulation of products and materials at their highest values and regenerating nature. In a circular economy, materials never become waste and are kept in circulation (EMF, n.d.-b). EMF visualized the concept of a circular economy through a *butterfly diagram* (EMF, n.d.-c) as in Figure 1. A transition from a linear to a circular economy is not merely about reducing waste generation and increasing waste recovery, but rather, coordinating a systematic shift of the economy with the aim of ultimately eliminating waste disposal through material circularity. Figure 2 illustrates the difference between linear, recycling and circular economies.

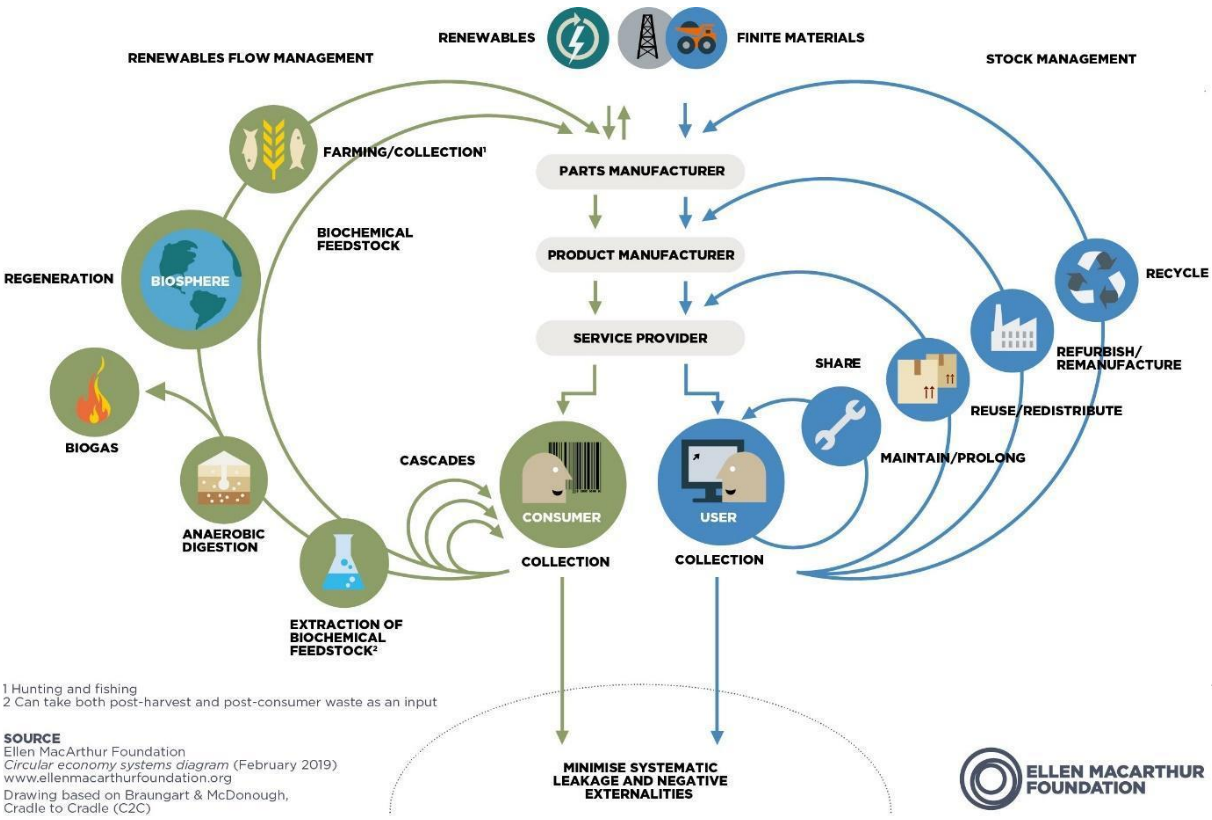

Figure 1: The *butterfly diagram* (Ellen MacArthur Foundation, n.d.-c)

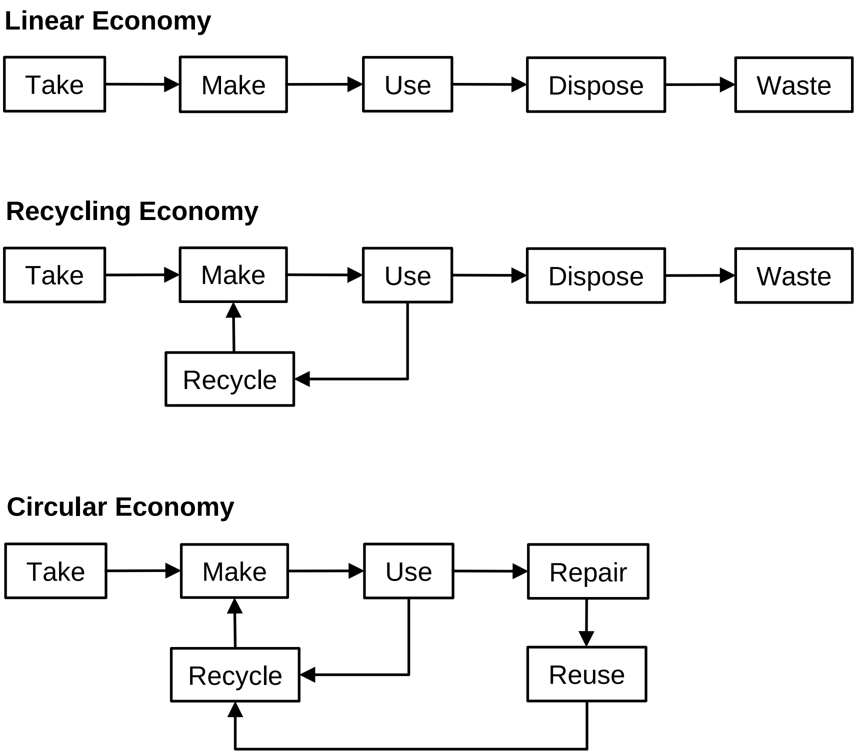

Figure 2: Difference between linear, recycling and circular economies

Role of Asia-Pacific Economic Cooperation (APEC) in the Transition to a Circular Economy

Asia-Pacific Economic Cooperation (APEC), as a regional economic forum that represents about 60% of the global GDP (Singh, 2020), can play a key role in the transition to a circular economy at global, regional and local scales. In the 2014 Leader's Declaration at the 22nd APEC Economic Leaders' Meeting in Beijing, People's Republic of China as shown in Figure 3, the concept of a circular economy was first mentioned as part of the creation of the New Economy that endeavours to advance economic growth coupled with sustainable development (APEC, 2014). The transition to a circular economy presents an opportunity for APEC members to contribute to global sustainability by supporting the Sustainable Development Goals (SDG) of the United Nations 2030 Agenda for Sustainable Development (United Nations, 2015), particularly SDG8 (Decent Work and Economic Growth) and SDG12 (Responsible Consumption and Production). The endeavour is beneficial for APEC economies in working towards meeting the sustainability targets reaffirmed during the United Nations Climate Change Conference in 2021 or 26th Conference of the Parties (United Nations, 2021) hence contributing towards advancing the implementation of the Paris Agreement (United Nations, 2015).

Figure 3: Photo at the 22nd APEC Economic Leaders' Meeting in Beijing, People's Republic of China (APEC, 2014)

Solid Waste in the APEC Region

According to the World Bank (Kaza *et al.*, 2018) and APEC Policy Brief No. 30 (Singh, 2020), APEC economies contributed about 43% of the global solid waste in 2016, 59% of which was mismanaged. About 66% of the mismanaged waste originated from developing economies. Furthermore, daily solid waste generation per capita in the developing economies has been projected to increase by 46% between 2016 and 2050.

In order to concurrently address the concerns with regard to the high solid waste generation rate as well as the high resource consumption rate of the construction industry, valorization of the solid waste for manufacture of construction materials has to be promoted. As solid waste is generated from multiple industries, inclusive of CDW that is generated from the construction industry, an innovative approach that involves the waste management collaboration between the construction industry and other sectors that contribute to solid waste generation is required.

Promoting Circular Economy in the Construction Industry within the APEC Region

A project has been initiated under APEC PPSTI to develop a conceptual framework for promoting circular economy in the construction industry within the APEC region. The framework adopts an industrial symbiosis approach that involves a synergy between different organizations.

The idea to adopt an industrial symbiosis approach was inspired mainly by the success of the Kalundborg Symbiosis in Kalundborg, Denmark (Kalundborg Symbiosis, 2024), where a synergy between public and private companies was established to adopt a circular economy approach to production as presented in Figure 4. There are applications of industrial symbiosis in the Asia-Pacific region, which include the city of Kwinana in Australia (Kwinana Industries Council, n.d.) and CleanTech Park in Singapore (Enterprise Singapore, 2023). Although there are other examples of industrial symbiosis in other parts of the world as well as in research, the applications are not focused on valorizing waste for the manufacture of construction materials and promoting circular economy in the construction industry.

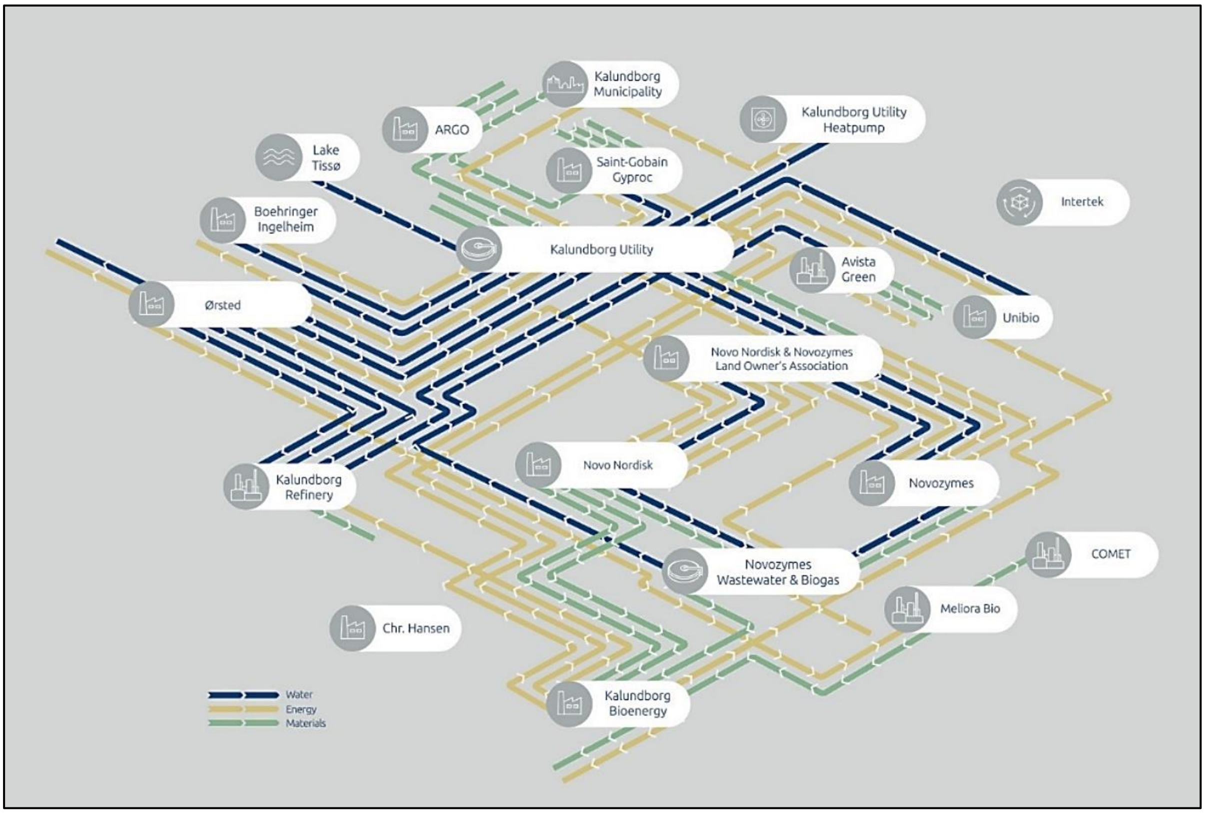

Figure 4: Synergy between public and private companies in Kalundborg Symbiosis (Kalundborg Symbiosis, 2024)

Analysis of Data on Waste Management

Data on waste management were obtained from the governments of the selected economies through various sources. The main sources are listed in Table 1. Additional data were also obtained from the report of the United Nations Environment Program and Asian Institute of Technology (2017). The data were analyzed to obtain the annual solid waste generation, daily solid waste generation per capita and waste recycling rate. The analysis is performed on the latest yearly data available for each economy as the availability of the data is limited. The data years range from 2019 to 2022.

Table 1: Main sources of waste management data according to economy

Economy	Sources
Australia	Australian Bureau of Statistics (2022) Pickin *et al.* (2023)
Indonesia	BPS-Statistics Indonesia (2023) Indonesia, Ministry of Environment and Forestry, National Waste Management Information System (2023)
Malaysia	Malaysia, Ministry of Economy, & Department of Statistics (DOSM) (2023a) Malaysia, Ministry of Economy, & DOSM (2023b) Malaysia, National Solid Waste Management Department (2013)
The Philippines	Philippines Statistics Authority (2021) Philippines Statistics Authority (2022) The Philippines, Environmental Management Bureau (2024)
Singapore	Singapore, Department of Statistics (2022) Singapore, National Environment Agency (2022)
Chinese Taipei	Chinese Taipei, Ministry of Environment (2023) Chinese Taipei Statistics (2023)
Thailand	National Statistical Office of Thailand (2022) Thailand, Pollution Control Department (2022)

The annual solid waste generation in the selected economies is illustrated in Figure 5. The amounts of generation range from 7.39 to 75.80Mt. The highest and lowest amounts are obtained by Australia and Singapore, respectively. In comparison to the other economies, the amounts of 75.80 and 68.50 Mt obtained by Australia and Indonesia, respectively, are considerably high. The other economies obtained amounts of up to 32.42Mt. Although it is apparent that waste management greatly influences waste generation, population size and density as well as seasonal variations and tourism throughout the year also influence the amount of generation.

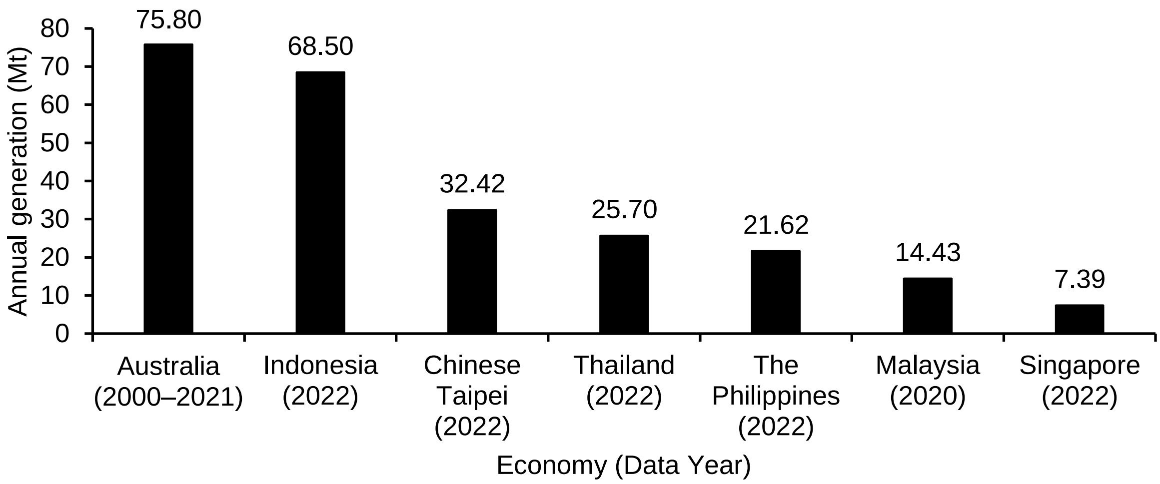

Figure 5: Annual solid waste generation in selected economies

On top of the amounts of generation, the rates also have to be analyzed. Hence, values of daily solid waste generation per capita are determined and illustrated in Figure 6. The values of generation per capita range from 0.53 to 8.06kg/capita/day. The highest and lowest values are obtained by Australia and the Philippines. The highest value of 8.06 kg/capita/day is considerably high in comparison to the values obtained by the other economies, which range from 0.53 to 3.82 kg/capita/day.

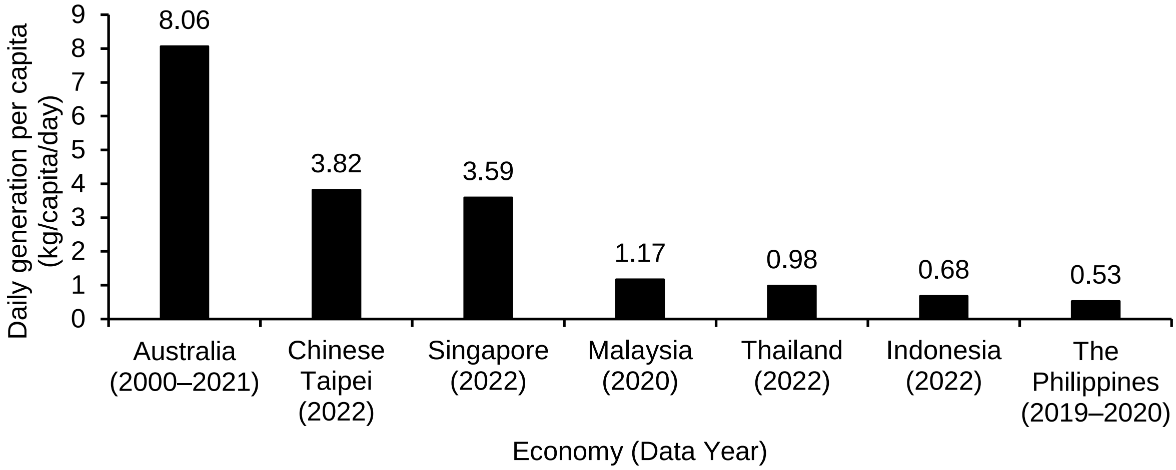

Figure 6: Daily solid waste generation per capita in selected economies

Recycling is already being implemented in the economies in an effort to reduce the solid waste generation, in spite of facing various complications and limitations with regard to the implementation of a recycling economy. The recycling rates are revealed in Figure 7, which comprises the rates of all selected economies, except for that of the Philippines, as the availability of the data is limited. Data on the recycling of materials in the Philippines are limited to a study conducted in 2008 by Japan International Cooperation Agency (2008), which is considered as unfitting for the analysis. The rates range from 15 to 75%. The highest and lowest amounts are obtained by Chinese Taipei and Indonesia, respectively.

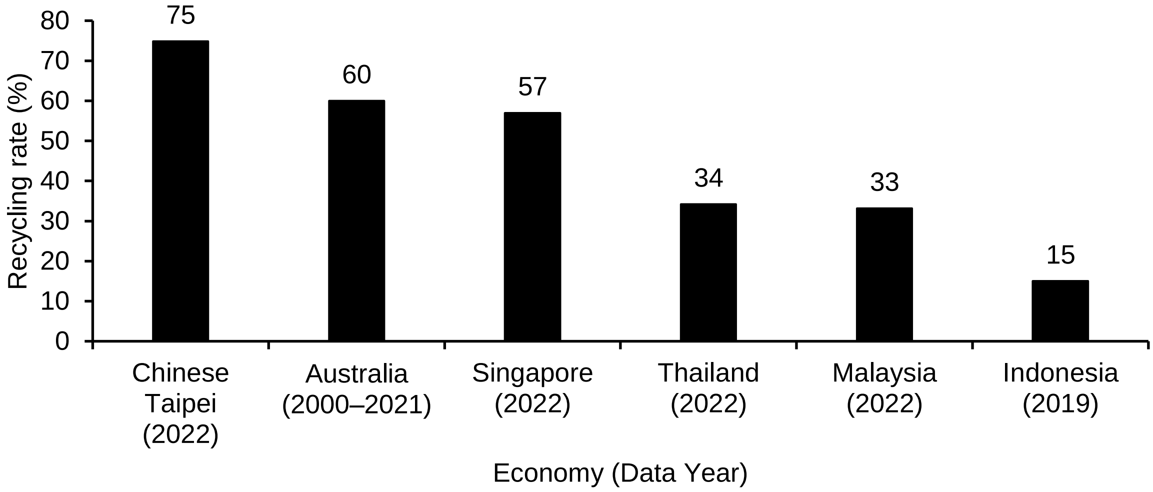

Figure 7: Solid waste recycling rates in selected economies

Questionnaire Survey among Construction Industry Stakeholders

The questionnaire survey aims to gather perspectives among construction industry stakeholders from APEC economies on different aspects pertaining to the valorization of solid waste for the manufacture of construction materials and the promotion of circular economy in the construction industry within the economies using the industrial symbiosis approach. Six stakeholder categories were identified, which are public client, private client, contractor, consultant, manufacturer and academic or research institution. A thorough review of numerous recent and relevant studies was conducted in order to design the questionnaire and identify the stakeholder categories. The questionnaire was designed with the aim of gathering perspectives, based on working experiences, on different aspects pertaining to the valorization of solid waste for the manufacture of construction materials and the promotion of circular economy in the construction industry within the economies.

Perspectives are gathered on the following aspects pertaining to the valorization of solid waste for the manufacture of construction materials:

1. Waste types that have a significant impact on CDW generation
2. Waste types that are commonly valorized to manufacture construction materials
3. Percentage of construction materials that, throughout construction and demolition, ends up as CDW
4. Percentage of CDW that can be valorized to manufacture construction materials
5. Construction materials that can be manufactured from waste

Perspectives are gathered on the following aspects pertaining to the promotion of circular economy in the construction industry within the economies:

1. Implementation of efforts within the organization of the respondent
2. Importance of aspects with regard to the manufacture of construction materials
3. Importance of aspects with regard to the recovery of construction materials
4. Importance in addressing challenges with regard to the manufacture of construction materials
5. Importance in addressing challenges with regard to the recovery of construction materials
6. Importance in addressing challenges with regard to awareness and understanding
7. Importance in addressing business challenges
8. Importance in addressing economic challenges

A total of 122 responses were received as revealed in Annex A. The responses were received from construction industry stakeholders of 12 APEC economies: Australia; Brunei Darussalam; Chile; People's Republic of China; Hong Kong, China; Indonesia; Malaysia; the Philippines; Singapore; Thailand; The United States; Viet Nam. The responses were obtained from all six categories of the construction industry stakeholders and are of a wide age range. All stakeholders possess experience working for the construction industry. The levels of experience working in the construction industry and on circular economy vary. The participation of stakeholders of varying stakeholder categories, age ranges and experience levels allow for the opportunity to obtain a broad perspective albeit focused on the construction industry.

Responses from the stakeholders reveal that a wide range of waste types has the potential to be valorized to manufacture a wide range of construction materials at substantial amounts, as revealed in Annex B. The responses suggest that concrete and asphalt waste, building and demolition debris, and wood and lumber scraps have the highest potential for valorization, while bricks, cement and concrete, wood and steel have the highest potential to be manufactured from waste. The responses imply that up to 50% of construction materials, throughout the construction and demolition of most projects, ends up as CDW, where 75% of the CDW can be valorized to manufacture construction materials.

According to the responses in Annex C, the implementation of efforts to adopt circular economy has started in most construction industry organizations, although the levels of implementation are mostly elementary. Most organizations have started developing circular economy strategies and new business models based on the circular economy as well as training employees and working with the supply chain to adopt the circular economy. The responses also reveal the importance of considering several aspects with regard to the manufacture and recovery of construction materials in adopting the circular economy and addressing several challenges that could hinder the adoption.

The aspects with regard to the manufacture of construction materials are using less hazardous materials, increasing the life span of materials, designing for disassembly, designing for standardisation and using more secondary materials. The challenges are the lack of secondary materials, lack of incentive to design for the end of life of materials and lack of alternative options to replace hazardous materials. The aspects with regard to the recovery of the materials are reusing the materials, recycling the materials, keeping the materials within the same sector, using the materials across different sectors and keeping the materials at the highest value possible. The challenges are the downcycling of materials, limited options for reuse of materials, lack of market mechanisms and hazardous properties of materials.

Other than the challenges with regard to the manufacture and recovery of construction materials, the responses imply that addressing challenges with regard to awareness and understanding, business challenges and economic challenges are also considered as important. The challenges with regard to awareness and understanding are the lack of awareness on circular economy within the organization, lack of awareness on circular economy across the supply chain, lack of understanding on circular economy and lack of interest towards adopting circular economy. The business challenges are the difficulty in measuring circularity, fragmented supply chain, unclear ownership of materials and limited viable business models. The economic challenges are the unclear financial case, depreciation of assets across the building lifecycle, low value of materials at the end of life.

Engagement Workshop with Experts and Stakeholders

A virtual workshop was held for three days from 27 to 29 February 2024, for four hours per day from 9:00 a.m. to 1:00 p.m., (Malaysia standard time) based on the agenda presented in Annex D. The purpose of conducting the workshop is to engage with circular economy and construction industry experts and stakeholders to enhance the maturity of the conceptual framework. The workshop gathered four expert speakers and 34 active participants. Biodata of the speakers are presented in Annex E. The speakers and participants comprise personnel from government agencies, academic and research institutions, and construction industry stakeholders from 10 APEC economies: Australia; Brunei Darussalam; Chile; Malaysia; Peru; the Philippines; Singapore; Thailand; The United States; and Viet Nam.

The workshop commenced with opening remarks from Prof. Dr. Nasir Shafiq, the Project Overseer. The need to acknowledge the criticality of issues faced globally, owing to the present state of the construction industry as the primary consumer of natural resources, was stressed. Resource depletion was highlighted as an issue that has reached a critical level and can no longer be neglected. The urgency to address the inefficiency of the linear economy, as presently adopted in the construction industry, was emphasized. The workshop program was then introduced. The experts and stakeholders were encouraged to engage in the discussions by sharing knowledge and experience as well as expressing thoughts and ideas. A research background paper was circulated to the experts and stakeholders prior to the workshop and used to guide discussions throughout the workshop.

Ts. Dr. Syed Ahmad Farhan bin Syed Ahmad Iskandar, the Research Contractor of the project, then presented the findings of the pre-workshop survey. Data on solid waste management and responses on perspectives of construction industry stakeholders were presented. Opportunity for further enquiry on the findings was given to spark discussions.

The workshop was then divided into four sessions on different aspects pertaining to the adoption of circular economy in the construction industry, with case studies from different APEC economies. Session 1 focused on the application of products with recycled content (PwRC) in construction projects, with case studies from Australia. Session 2 focused on the recycling of municipal sewer sludge (MSS) as construction material, with case studies from Viet Nam. Session 3 focused on the adoption of digital construction to minimize CDW through material optimization, with case studies from Indonesia, Malaysia and Singapore. Session 4 focused on state-of-the-art initiatives for the construction industry, with case studies from Chile.

Session 1: Application of Products with Recycled Content in Construction Projects

Session 1 was delivered by Dr. Salman Shooshtarian, a senior lecturer and a researcher from School of Property, Construction and Project Management, RMIT University, Australia.

Dr. Salman highlighted that the architecture, engineering and construction sector is responsible for 40% of solid waste production throughout the world. The sector contributes a 9% share of the total gross domestic product in Australia. Waste in Australia is regulated at state level. Based on the National Waste Report of Australia (Pickin *et al.*, 2023), domestic CDW recovery rate is 78% in 2020–2021 hence has improved relative to previous years.

In an effort to further improve the domestic CDW recovery rate, Dr. Salman and his research team have been conducting studies on the application of PwRC in construction projects in Australia. Findings of the studies revealed the barriers that hinder the application, factors that motivate the application and strategies to address the barriers, as outlined in Table 2.

Table 2: Insights from findings of the studies on the application of products with recycled content (PwRC) in construction projects in Australia

Barriers that hinder the application	• Unsupportive regulations • Inconsistency of PwRC quality performance and warranty • Limited availability of PwRC • Lack of expertise and understanding in using PwRC
Factors that motivate the application	• Environmental benefits • Ensuring competitive advantage • Future proofing
Strategies to address the barriers	• Effective education, investigation and demonstration activities • Effective project management planning

Dr. Salman stressed that, although the findings provide useful insights into the application of PwRC, precise planning for using PwRC are subjected to contextual variables, including evident and latent constraints and opportunities. Motivation for using PwRC may differ from one stakeholder to another. Therefore, differences in the motivation have to be acknowledged and taken into consideration when making changes to the status quo in an effort to encourage the application of PwRC.

Dr. Salman further enlightens on the efforts being made in Australia to frequently update policies to promote the application of PwRC. Material specifications for a broader array of PwRC are being developed. There are state-based organizations that actively promote the application of PwRC, such as ecologiQ (Australia, State Government of Victoria, 2024), Waste Forum (Riverina Eastern Regional Organisation of Councils, 2018) and Green Industries SA (Australia, State Government of South Australia, 2024). Marketplaces have been developed to connect suppliers of recycled materials with buyers. Environmentally Sustainable Procurement Policy (Australia, Department of Climate Change, Energy, the Environment and Water, 2024) encourages government organizations to set targets for using PwRC in public projects. Numerous funding opportunities have been created to bolster the ability of state-based organizations in Australia to supply PwRC sustainably. Educational content is being developed to raise stakeholder awareness on the application of PwRC.

Dr. Salman highlighted Burwood Brickworks, a shopping centre in Victoria, Australia, which has been branded as the world's most sustainable shopping centre. There are many examples of the application of PwRC in the project: crushed concrete was repurposed in the sub-base of bitumen; materials from slab form were repurposed as hanging timber and timber cladding in the ceiling; second-hand bricks were repurposed as tiles and concrete in floors; crushed brick leftover was repurposed as finishing material for facades.

Session 2: Recycling of Municipal Sewer Sludge as Construction Material

Session 2 was delivered by Assoc. Prof. Ir. Dr. Huyền Đặng Thị Thanh, an associate professor and a researcher from Water Supply and Sanitation Division, Faculty of Environmental Engineering, Hanoi University of Civil Engineering, Viet Nam.

Dr. Huyền highlighted that Viet Nam produced 15–245 tons of MSS per year from sewer and drainage system, open canals, internal rivers and lakes and wastewater treatment plants, where the majority of MSS is disposed of at dumping sites and only a small percentage is reused as construction material.

In essence, developing processes for production of construction materials based on efficient use of resources and environmental protection is part of the strategy for sustainable growth. Studies have been conducted on the use of various types of waste as raw material and fuel to produce construction materials. A target for the development of Viet Nam has been set for approximately 30 billion units of construction material to be produced by 2030.

For MSS with low organic content, such as that from drainage networks at upstream areas, which has high sand and gravel contents, the potential for blending with cement has been considered to produce non-fired construction material and filling material. Non-fired brick produced with the reuse of MSS can be applied as surrounding brick fence, high-class interior and exterior brick, Terrazzo brick for paving sidewalks, wall bricks in industrial houses and tiles. On the other hand, MSS with medium to high organic content can be reused to produce fired brick, which can be applied similarly to the fired clay brick that is already in the market, as brick wall, load-bearing partitions and foundation.

Energy consumption during the production of brick with the reuse of MSS is restricted. For fired brick, thermal energy consumption is restricted at 360kcal/kg and below, while electrical energy consumption is restricted at 0.022kWh/kg and below. For non-fired brick, synchronized production lines with high levels of mechanization and automation are employed to reduce energy consumption.

MSS can be reused as filling material, particularly in concrete and asphalt concrete pavements. It also can be converted to solidified sludge for reuse in combination with cement and lime as base and sub-base layers in road construction.

Dr. Huyền highlighted the barriers that hinder the reuse of MSS in Viet Nam, which include economic viability, public perception, quality control, regulatory compliance, research and development, technology and infrastructure, and waste management. In order to address the barriers, collaboration among government agencies, research institutions, industry stakeholders and communities is essential to develop effective policies, technologies and practices for sustainable reuse of MSS, particularly in the production of bricks.

Session 3: Adoption of Digital Construction for Material Optimization

Session 3 was delivered by Ts. Andy Tiong Meng Jun, a member of Technology and Technical Working Group (Building and Construction Technology), Malaysia Board of Technologists, Malaysia.

Ts. Andy recommended a solution by minimizing waste through material optimization. The solution adopts the integrated digital approach instead of the conventional approach to construction. An integrated environment is put in place, where Building Information Modelling (BIM), pre-fabrication, pre-casting and automation are adopted. Through the integrated environment, optimization can be achieved, where material use can be maximized hence, sustainability is promoted.

Ts. Andy explained that the conventional approach adopted at present consumes a lot of money, energy, material and time. Application of BIM in the construction industry can facilitate visualization from the 2D drawing to the 3D model. However, BIM models are not fully optimized due to individuals and departments working in silos. Dynamic planning amidst the existing environment is beneficial for better traffic and access planning.

Ts. Andy then presented the idea of pre-fabrication, which can optimize the raw material and shorten delivery times. However, drawbacks may arise if the sequence is not properly planned. Ts. Andy elaborated on the approach of leveraging the current built data through the adoption of integrated digital construction. The design is created based on construction requirements rather than system requirements. Through dynamic planning, multi-disciplinary collaboration can be formed for better insight.

Ts. Andy demonstrated the concept of using augmented reality to validate the 3D model in the actual environment. The data generated can be shared with consultants to create opportunities to avoid rework. Reality mapping can be used to obtain context capture from aerial shots. Overlaying the 3D model to the actual site condition using augmented reality aids in measuring areas that are difficult to access. The data collected allows for machine learning that can simulate and produce powerful end results.

Ts. Andy also demonstrated the concept of using virtual reality walkthrough to plan for the subsequent verification of the BIM site and enhance procurement approach with vendors. Construction rehearsal can be conducted using the digital data to perform on-site simulation and optimize the project delivery. Visual planning in construction is beneficial as it allows for more effective resource allocation.

Session 4: State-of-the-Art Initiatives for the Construction Industry

Session 4 was delivered by Ms. María Fernanda Aguirre Bustos, Chief Executive Director of Chile Green Building Council, Chile.

Ms. María highlighted that the waste generation rate in Chile is the second-highest in Latin America. Chile is the first economy in Latin America to establish, by law, a carbon neutrality goal by 2050, established in the Climate Change Framework Law published on 13 June 2022. Circular economy has been highlighted as one of the cross-cutting issues throughout the development of strategies for achieving carbon neutrality in Chile. Ms. María stressed that the integration of circular economy principles in the construction industry has to be performed at all stages of the construction life cycle. Each stage presents an opportunity to reduce waste by optimizing resource use as well as promoting reuse and recycling.

Ms. María demonstrated the use of a circularity calculator for micro and small businesses. It is developed as part of the Circular Territory program (Territorio Circular, 2024). It contains a 15-minute survey containing 20 questions on sustainable initiatives involving reuse, repair and recycling that can be implemented in businesses. It uses a scale of five response options, ranging from no implementation to full implementation of the initiative. Based on the responses, the calculator determines the level of circularity and categorizes the companies as expert, competent, aware or emerging. Progress is tracked and visualized to facilitate the companies to maintain their motivation to improve their level of circularity. Specific recommendations to improve the level of circularity are also provided.

Ms. María presented Sustainable Materials and Assets Passport (P+MAS), a project launched in April 2023 managed by Chile Green Building Council and Technological Centre for Innovation in Construction, Chile to develop material passports and real estate assets based on the registration of verified and validated information that supports attributes pertaining to circularity, environmental impact and toxicity. The project team also contemplates the development of an interface linked to BIM models and a carbon footprint assessment tool.

Workshop Evaluation

The impact of the workshop on the participants was evaluated. The evaluation comprises three sections: comprehension during discussions; gain of knowledge throughout the workshop; view on the workshop delivery; and perspective on the role of APEC in promoting circular economy in the construction industry. In general, the responses are positive for all sections, as revealed in Annex F.

Nonetheless, two suggestions were made for improvement of future workshops, which are to:

- increase the number of expert speakers
- increase the participation of government officials

Development of the Conceptual Framework

The conceptual framework is illustrated in Figure 8. The framework was developed using the findings obtained from the analysis of data on waste management, surveys and the engagement workshop with circular economy and construction industry experts and stakeholders. According to responses collected among circular economy and construction industry experts and stakeholders, 52.5% of the respondents are aware of some adoption of circular economy using industrial symbiosis in their local construction industry, while 47.5% of them are not aware of any cases of such adoption.

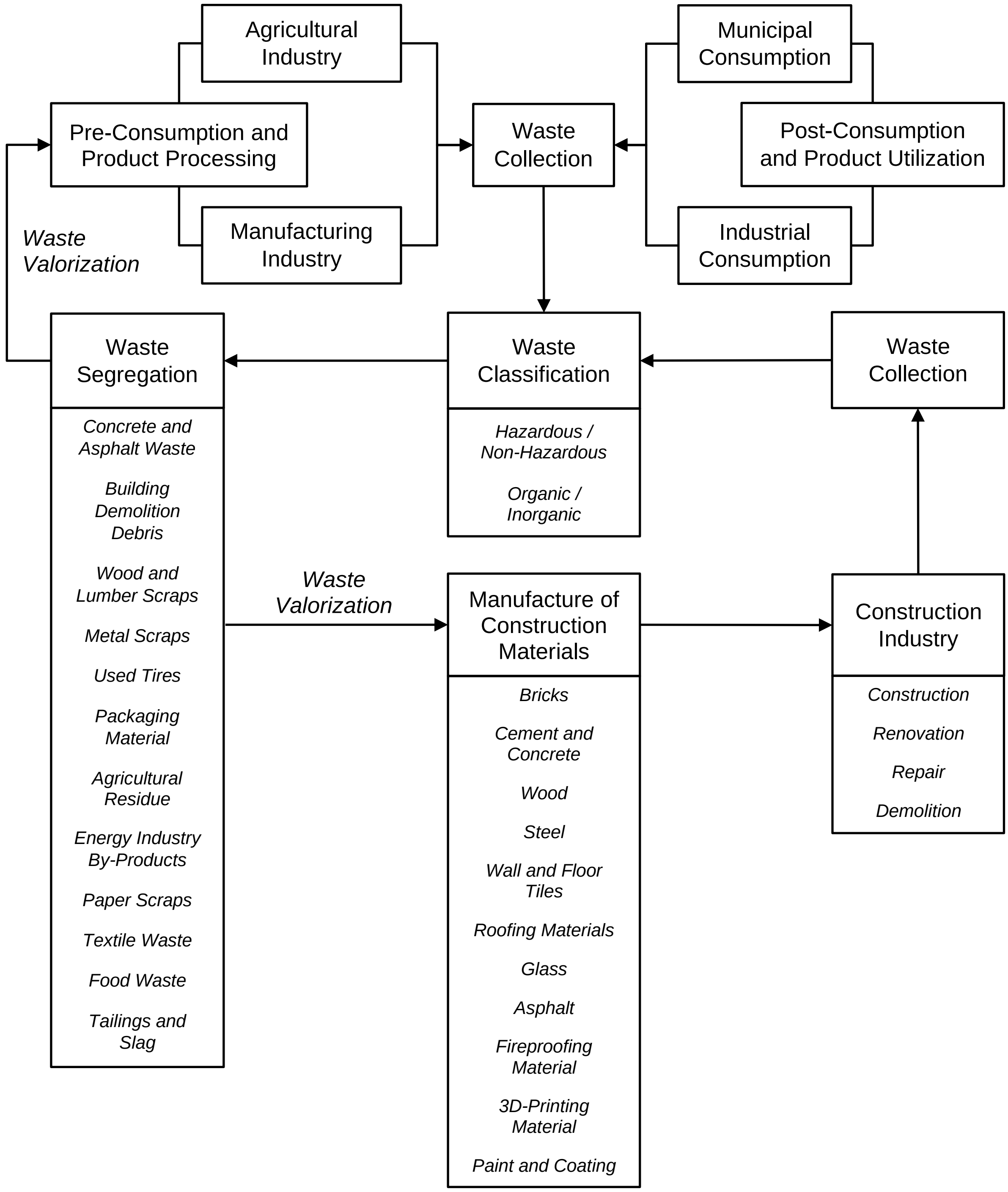

Figure 8: The conceptual framework using an industrial symbiosis approach

Solid waste generated from agricultural and manufacturing industries as well as municipal and industrial sources of consumption, along with CDW, are to be utilized as feedstock for manufacture of construction materials as well as other construction industry operations. An industrial symbiosis network of organizations from the agricultural, manufacturing, construction and waste management industries is to be established. The synergy among the organizations aims to concurrently eliminate solid waste disposal, fulfill the resource demand of the construction industry and prevent resource depletion.

There are challenges that have to be addressed for successful implementation of the framework. Based on the discussions held during the workshop, the primary challenges have been identified and are listed as follows:

- Reluctance to shift the mindset to adapt to circular economy practices owing to many years of adopting linear economy practices
- Resistance to change the business model due to perceived risks or uncertainty
- Increase in cost due to the need to reskill workers or hire new workers albeit in the short term
- Difficulty to attract investments due to the unclear economic case
- Lack of awareness on the importance of making the transition from a linear economy to a circular economy, particularly for the construction industry
- Lack of understanding on the concept of a circular economy, not only on its potential adoption in the construction industry, but also in general
- Barriers in technology, hindering the implementation of new technology that is required for recovering materials effectively
- Limited presence of authority that collects and segregates CDW according to different categories
- Inconsistent regulations or policies that do not incentivize or enforce circular economy practices
- Lack of clarity regarding metrics, indicators and performance baselines to assess circular economy practices
- Demand for circular products and activities may not yet be high among consumers or clients
- Lack of marketplaces for recovered materials
- Incorrect pricing of recovered materials
- Risk of dealing with recovered materials as standards in quality or perceived quality could drop
- Inadequate coordination and communication among different parties in the fragmented and complex value chain of the construction industry
- Difficulty to encourage cooperation and develop trust among multiple organizations as part of an industrial symbiosis network

Gender Statistics

The project promotes the economic empowerment of women by supporting four pillars: access to markets; skills, capacity building and health; leadership, voice and agency; and innovation and technology. Data that are disaggregated based on gender have been collected and are revealed in Figure 9. Best efforts have been made to establish diversity and inclusivity throughout the project.

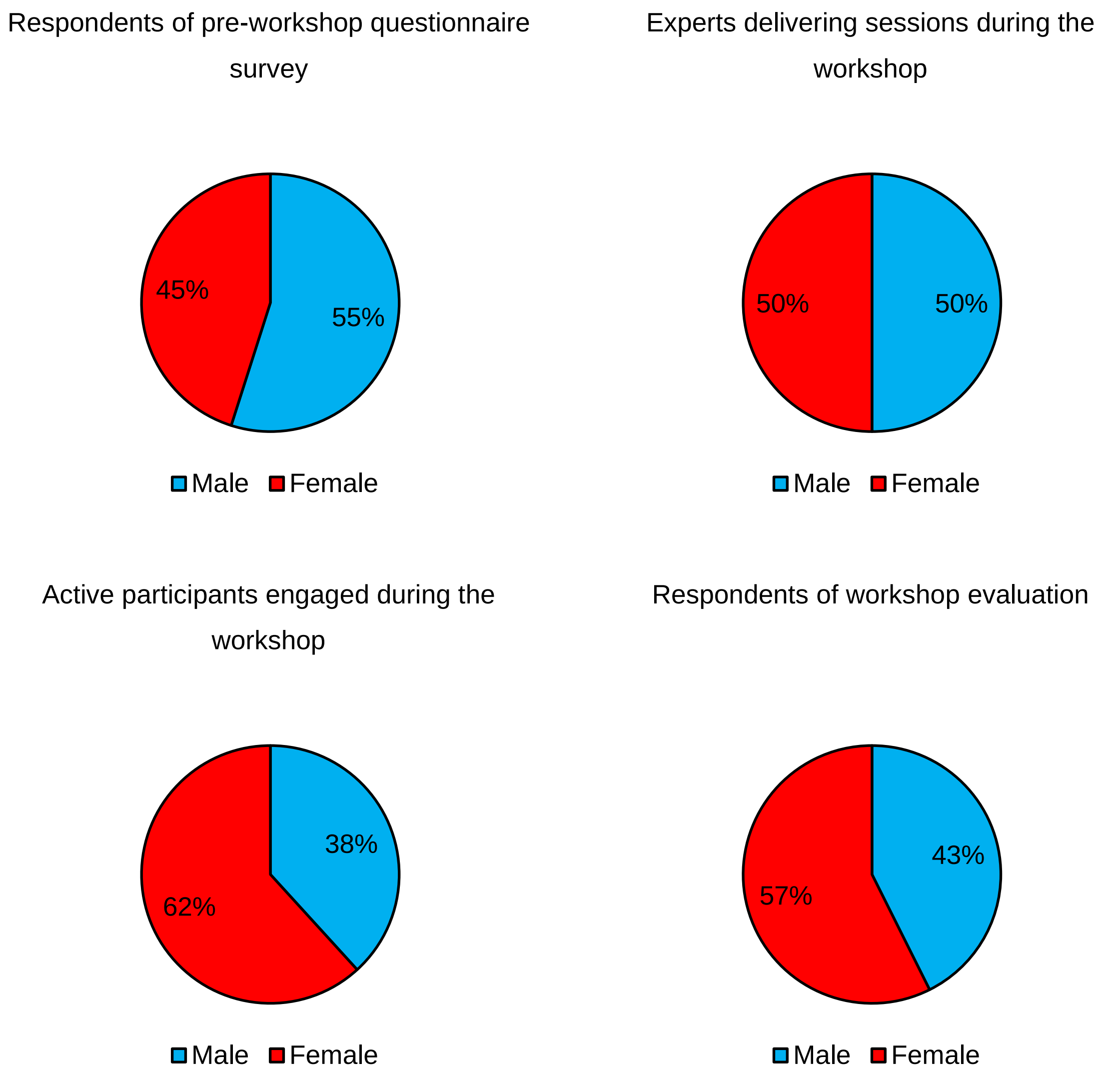

Figure 9: Gender statistics throughout the project

Conclusion and Recommendations

The project has been initiated under PPSTI to develop a conceptual framework for promoting circular economy in the construction industry within the APEC region using an industrial symbiosis approach.

Based on the findings of the analysis of data on solid waste management in the selected economies, the following conclusions can be made:

- Amounts of annual generation range from 7.39 to 75.80Mt.
- Values of daily generation per capita range from 0.53 to 8.06kg/capita/day.
- Recycling rates range from 15 to 75%.
- The industrial symbiosis approach presents an opportunity to maximize the recycling rates as a result of adopting a circular economy.

Based on the responses of construction industry stakeholders in the economies, the following conclusions can be made:

- With regard to aspects pertaining to the valorization of solid waste for the manufacture of construction materials, a wide range of waste types has the potential to be valorized to manufacture a wide range of construction materials at substantial amounts.
- With regard to the adoption of circular economy in the construction industry, implementation of efforts to adopt circular economy has started in most construction industry organizations, although the levels of implementation are mostly elementary. Important aspects with regard to the manufacture and recovery of construction materials in adopting the circular economy have been identified. Challenges that have to be addressed to enable the successful adoption of the circular economy have also been identified.

The conceptual framework is developed, where solid waste generated from agricultural and manufacturing industries as well as municipal and industrial sources of consumption, along with CDW, are to be utilized as feedstock for the manufacture of construction materials as well as other construction industry operations. An industrial symbiosis network of organizations from the industries is to be established.

There are challenges that have to be addressed for successful implementation of the framework. The primary challenges have been identified. In spite of the challenges, further depletion in resources coupled with further increase in the cost of resourcing construction materials resulting from the linear economy will put pressure on construction industry stakeholders to overcome the challenges and make the transition to a circular economy in the future.

Recommendations have been made to address the challenges for implementation of the framework as follows:

- Organize seminars, workshops and training programs that spread awareness, appreciation and understanding among government agencies, higher-learning and research institutions, industry stakeholders and communities in APEC economies on the concepts of circular economy and industrial symbiosis in the context of the construction industry
- Engage with government agencies, higher-learning and research institutions, industry stakeholders and communities in APEC economies to gain support and foster collaboration that promotes circular economy in the construction industry
- Develop standardization for recovered construction materials and products manufactured throughout the APEC region
- Establish passports for construction materials and products manufactured throughout the APEC region
- Set up circular economy marketplaces for construction industry stakeholders throughout the APEC region
- Develop circularity calculators for construction industry stakeholders throughout the APEC region
- Adopt integrated digital construction to minimize waste through optimization of materials in construction projects
- Program geographic-information-system-based tools that facilitates the coordination among construction industry organizations in an industrial symbiosis network by performing geospatial optimization

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Annex A: Number of Respondents of the Survey Based on Categories

Stakeholder Category

Stakeholder Category	Number of Respondents
Academic or Research Institution	29
Client (Public)	19
Client (Private)	18
Consultant	18
Contractor	22
Manufacturer	16
Total	**122**

Age Range

Age Range	Number of Respondents
21–25	22
26–30	22
31–35	22
36–40	20
41–45	14
46–50	11
51+	11
Total	**122**

Years of Experience Working in the Construction Industry

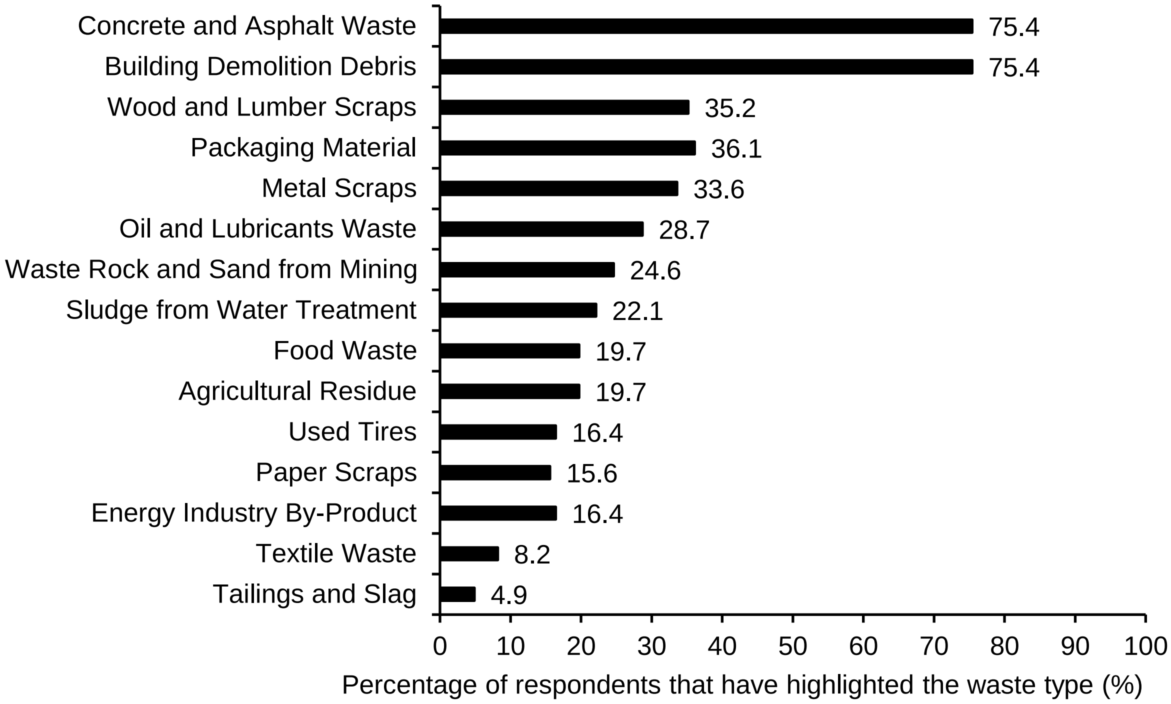
Years of Experience	Number of Respondents
1–5	64
6–10	12
11–15	15
16–20	11
20+	20
Total	**122**

Years of Experience Working on Circular Economy

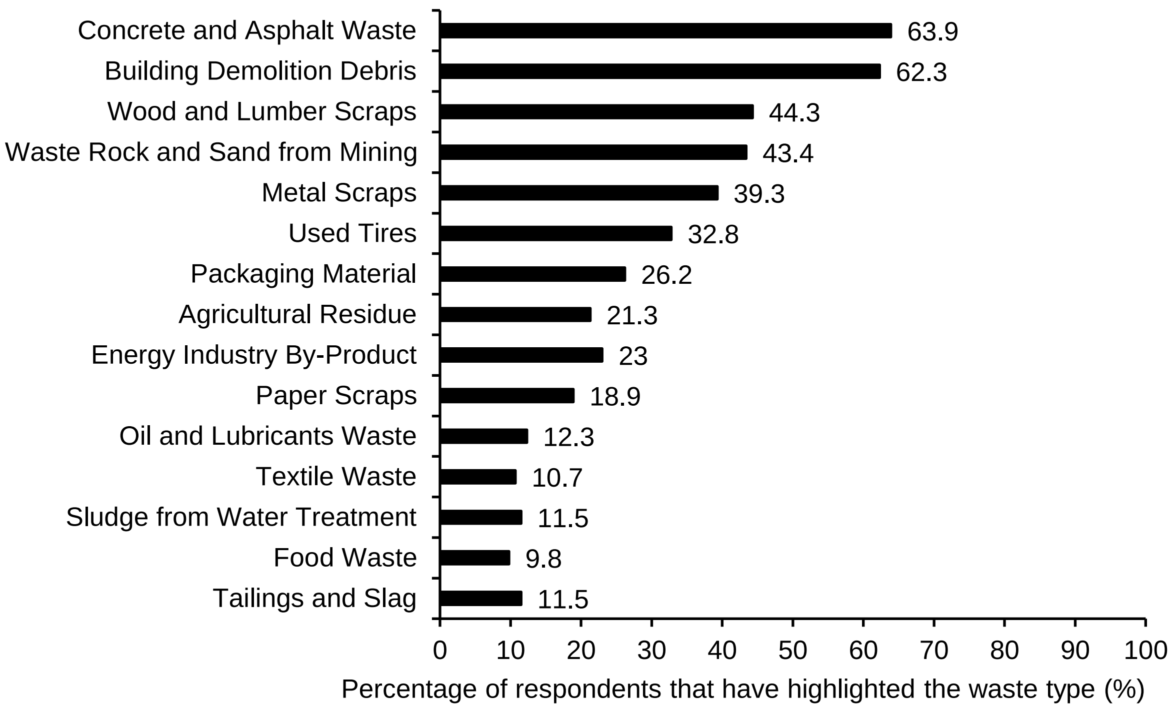
Years of Experience	Number of Respondents
0	25
1	27
2	11
3	13
4	9
5 and above	37
Total	**122**

Annex B: Perspectives with Regard to the Valorization of Waste to Manufacture Construction Materials

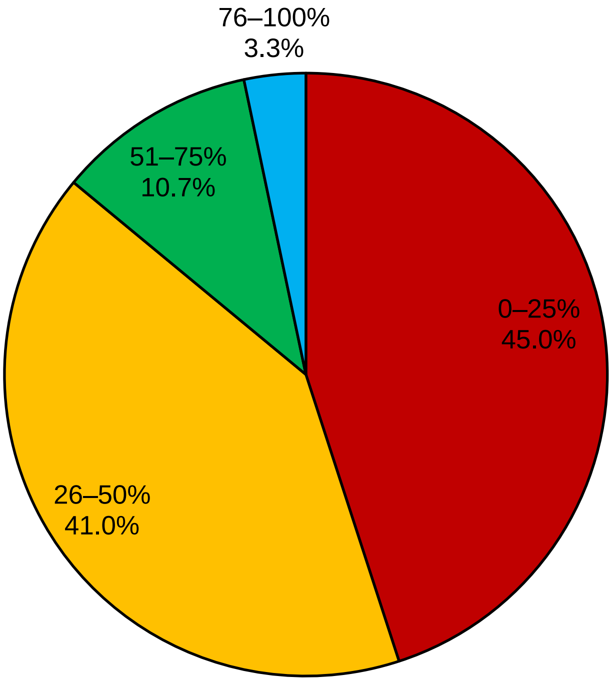
Waste types that have a significant impact on CDW generation



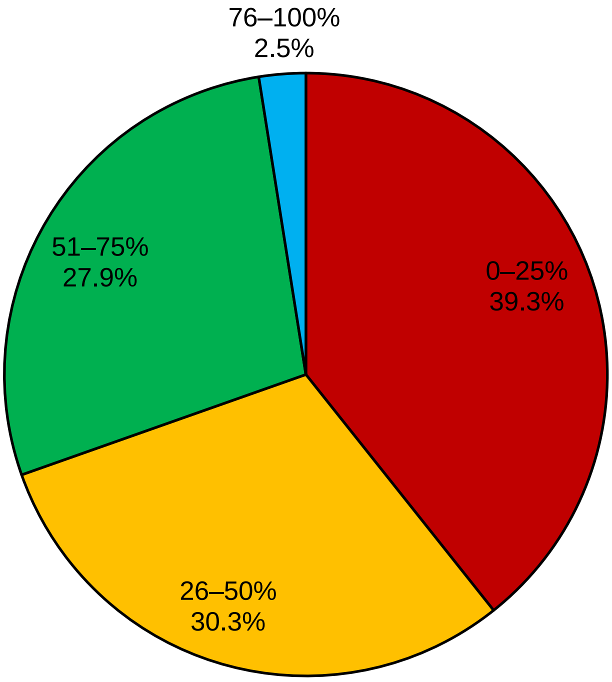
Waste types that are commonly valorized to manufacture construction materials



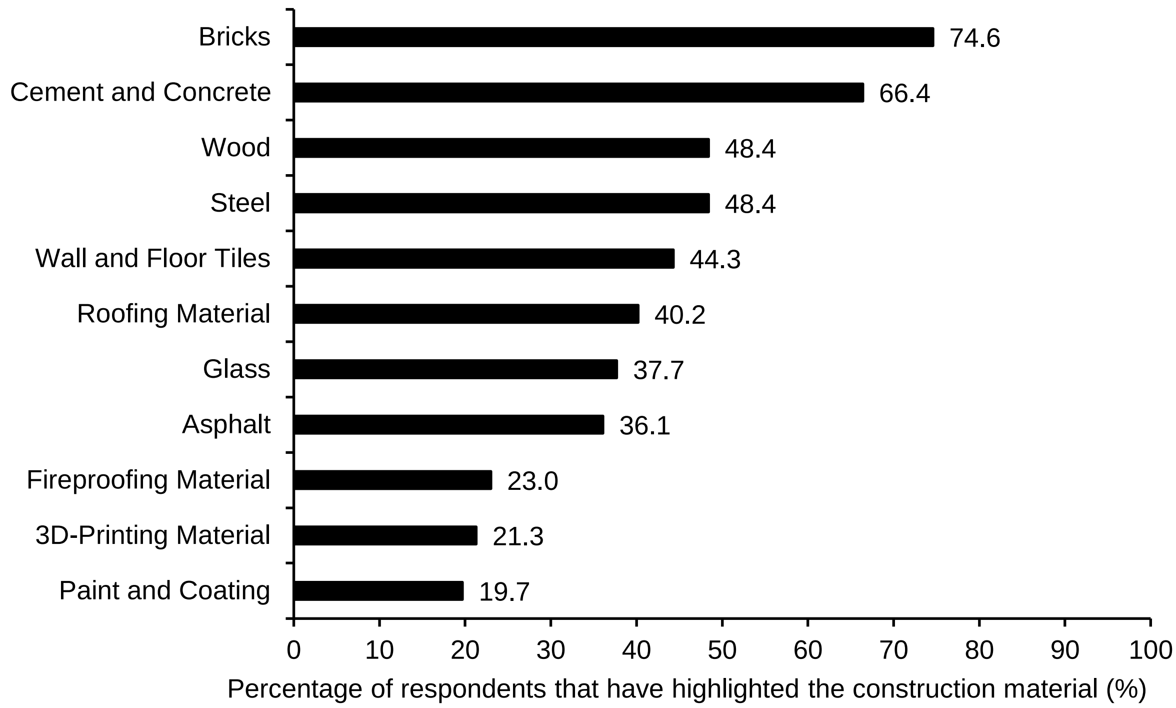
Percentage of construction materials that, throughout construction and demolition, ends up as CDW



Percentage of CDW that can be valorized to manufacture construction materials

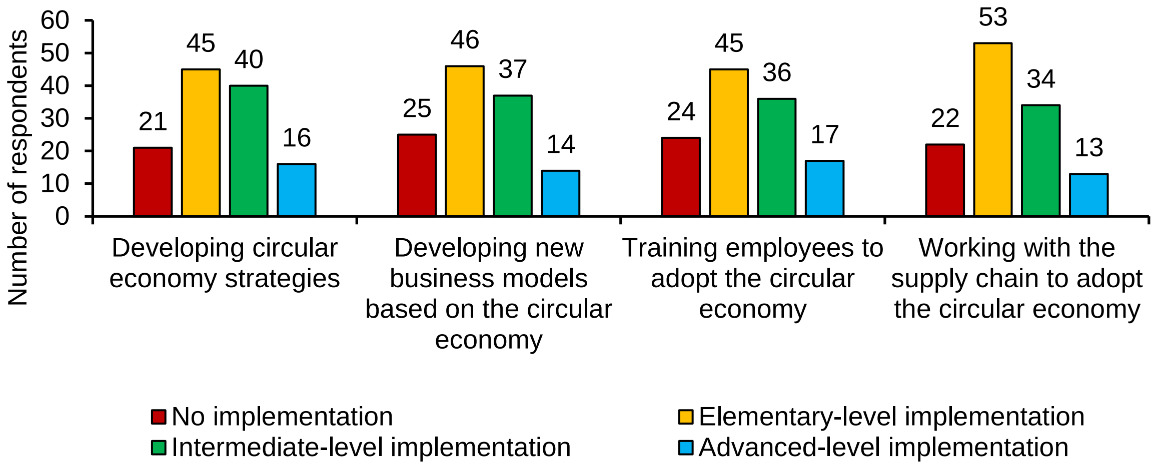


Construction materials that can be manufactured from waste

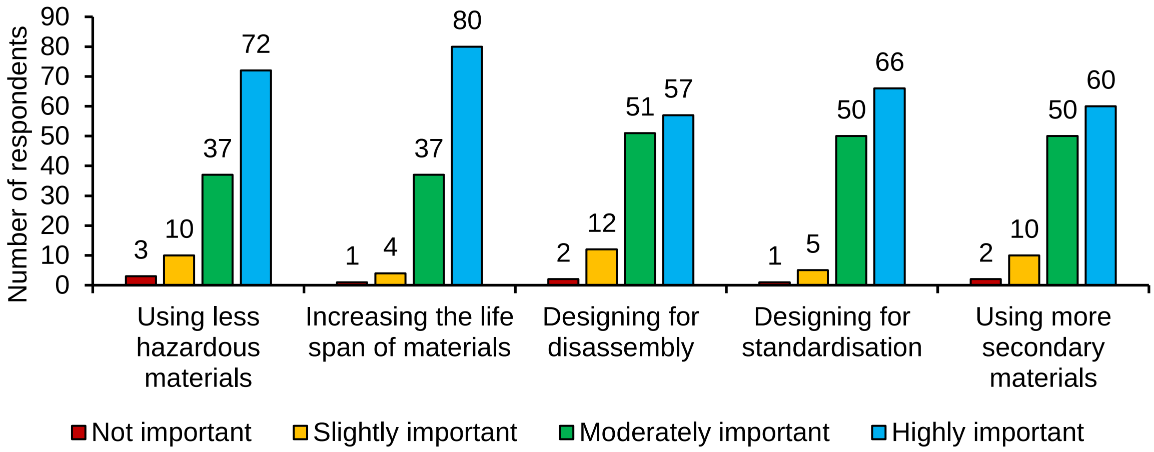


Annex C: Perspectives with Regard to the Adoption of Circular Economy in the Construction Industry

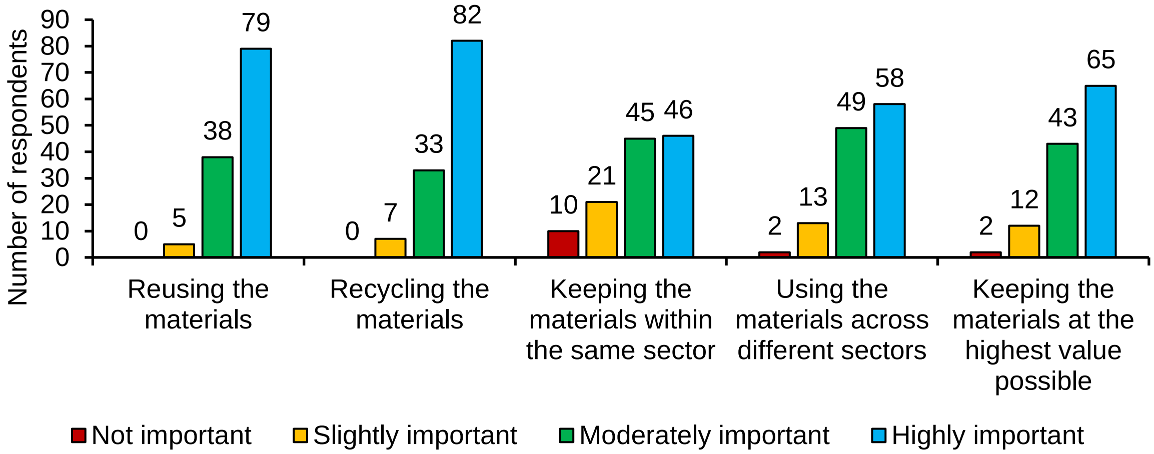
Level of implementation of efforts within the organization of the respondent



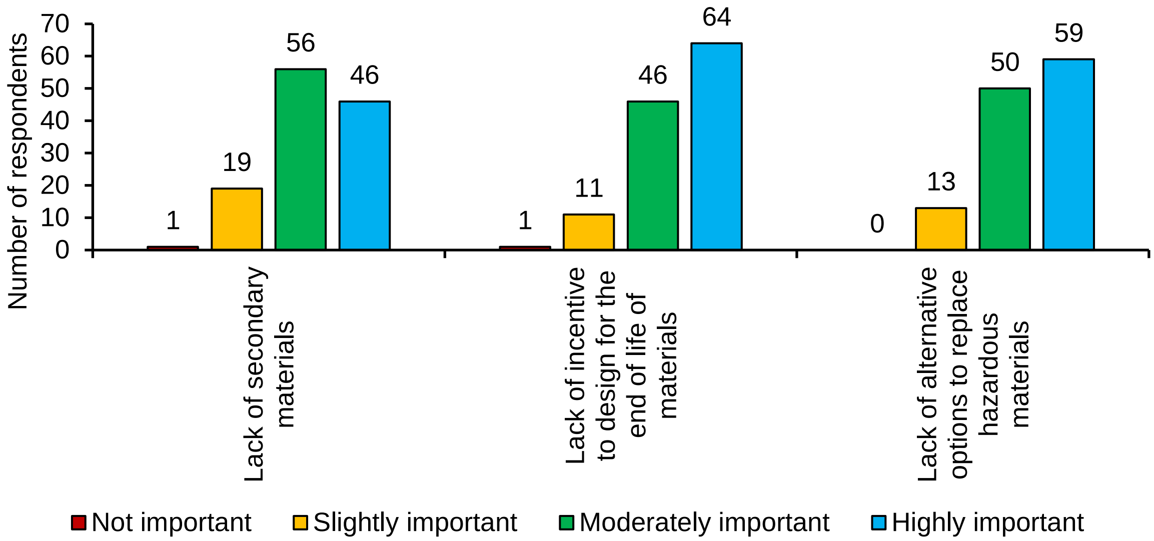
Level of importance of aspects with regard to the manufacture of construction materials



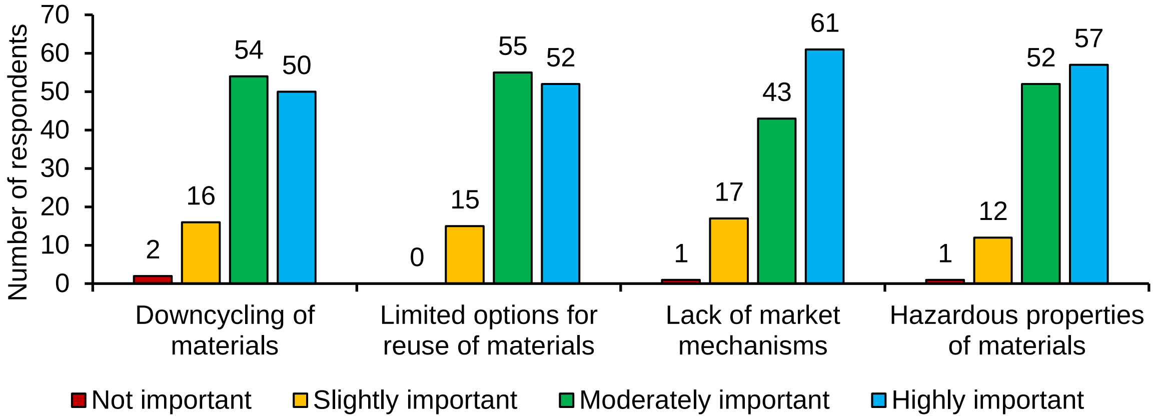
Level of importance of aspects with regard to the recovery of construction materials



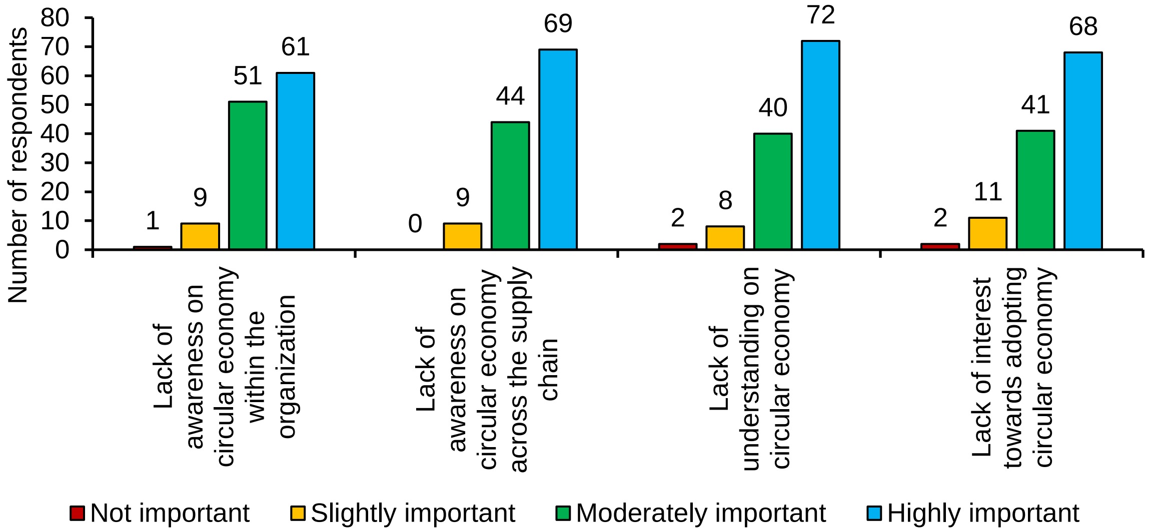
Level of importance in addressing challenges with regard to the manufacture of construction materials



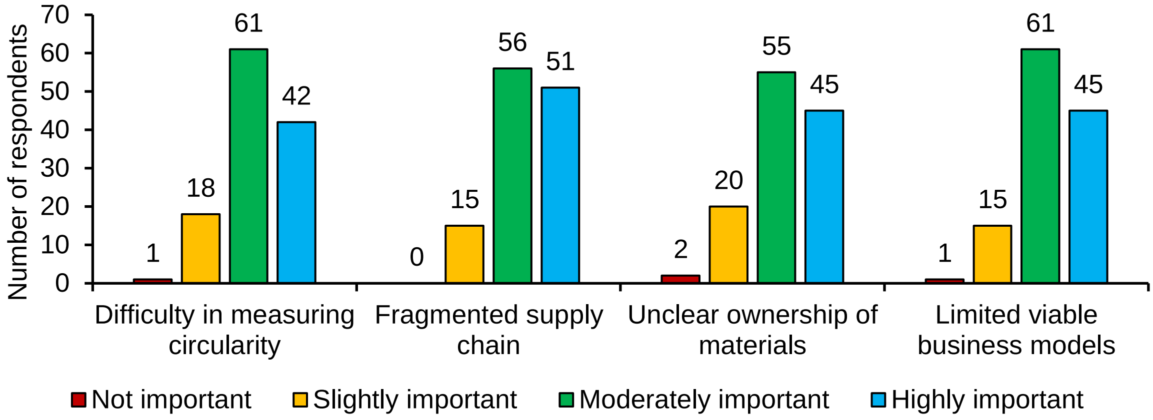
Level of importance in addressing challenges with regard to the recovery of construction materials



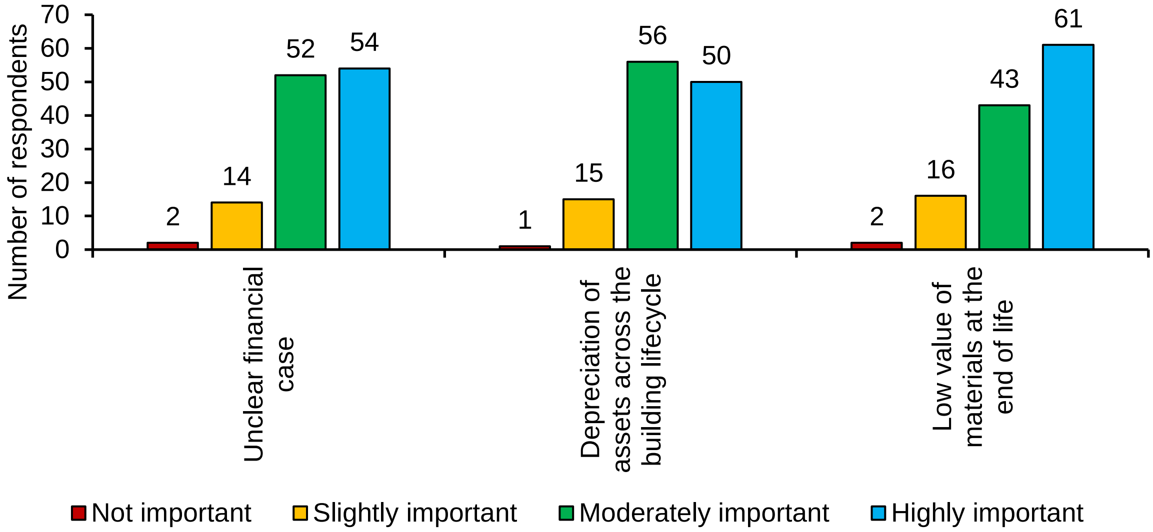
Level of importance in addressing challenges with regard to awareness and understanding



Level of importance in addressing business challenges



Level of importance in addressing economic challenges



Annex D: Agenda of Engagement Workshop

The times stated are based on the Malaysia standard time.

Day 1: 27 February 2024

0900–0915	Online registration of the expert speakers and active participants
0915–0930	Welcoming remarks by Prof. Dr. Nasir Shafiq, the Project Overseer, and handing over of the session to Engr. Ts. Dr. Vicky Kumar Lohana, the Moderator
0930–1030	Presentation by Ts. Dr. Syed Ahmad Farhan bin Syed Ahmad Iskandar, the Research Contractor, on the findings of the pre-workshop survey
1030–1045	Discussion on the findings of the pre-workshop survey
1045–1100	Break
1100–1200	Delivery of Session 1 by Dr. Salman Shooshtarian on the application of products with recycled content (PwRC) in construction projects
1200–1230	Discussion on the application of PwRC in construction projects
1230–1300	Consolidation of Day 1 by the Moderator

Day 2: 28 February 2024

0900–0915	Handing over of the session to the Moderator
0915–1015	Delivery of Session 2 by Assoc. Prof. Ir. Dr. Huyền Đặng Thị Thanh on the recycling of municipal sewer sludge (MSS) as construction material
1015–1045	Discussion on the recycling of MSS as construction material
1045–1100	Break
1100–1200	Delivery of Session 3 by Ts. Andy Tiong Meng Jun on the adoption of digital construction for material optimization
1200–1230	Discussion on the adoption of digital construction for material optimization
1230–1300	Consolidation of Day 2 by the Moderator

Day 3: 29 February 2024

0900–0915	Handing over of the session to the Moderator
0915–1015	Delivery of Session 4 by Ms. María Fernanda Aguirre Bustos on the state-of-the-art initiatives for the construction industry
1015–1045	Discussion on the state-of-the-art initiatives for the construction industry
1045–1100	Break
1100–1230	Discussion on the conceptual framework for promoting circular economy in the construction industry within the APEC region using an industrial symbiosis approach
1230–1300	Consolidation of Day 3 and closing remarks by the Project Overseer

Annex E: Biodata of Expert Speakers

Dr. Salman Shooshtarian

Dr. Salman Shooshtarian is a senior lecturer and a researcher from School of Property, Construction and Project Management, RMIT University, Australia. He holds a Ph.D in Built Environment from RMIT University, a Graduate Certificate in Construction Management from Deakin University and a Micro-Credential in Circular Economy & Sustainable Materials Management from Lund University. Prior to pursuing his Ph.D, he worked as a professional project manager on various green infrastructure projects in Iran for several years. He is a recognised expert in the field of construction and demolition waste management research with established industry links. Since 2018, he has successfully secured more than $500,000 in research grants, enabling him to lead cutting-edge research in the field. He is a member of the Waste Management and Resource Recovery Association of Australia and the Victoria Education Group. He has served as a research project manager on four domestic research projects from 2018–2023 funded by Australia Sustainable Built Environment National Research Centre, focusing on issues related to construction and demolition waste management. He is the lead author of the first Australian construction and demolition waste management book, published by Nova Science Publishers in 2021, designed to serve as a reference guide for Project Management and Construction Management students.

Assoc. Prof. Ir. Dr. Huyền Đặng Thị Thanh

Assoc. Prof. Ir. Dr. Huyền Đặng Thị Thanh is an associate professor and a researcher from Water Supply and Sanitation Division, Faculty of Environmental Engineering, Hanoi University of Civil Engineering, Viet Nam. She holds a Ph.D in Environmental Engineering from University of Ottawa. She worked for GE Water and Process Technologies, Canada for two years before joining Hanoi University of Civil Engineering, where she spends most of her time teaching and conducting research. She has more than 20 years of experience in environmental engineering in Canada and Viet Nam. Her main interest is to teach and conduct research in all aspects of environmental engineering, particularly water, wastewater and solid waste treatment and reuse. She has published about 60 articles related to these areas of research. She is a member of International Water Associations, Japan Society on Water Environment and Viet Nam Water Supply and Sewerage Association.

Ts. Andy Tiong Meng Jun

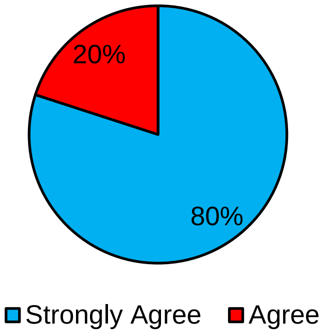
Ts. Andy Tiong Meng Jun a member of Technology and Technical Working Group (Building and Construction Technology), Malaysia Board of Technologists, Malaysia and the Director of Professional Services of PCSS Consultancy. He is a certified Project Management Trainer, delivering training to prominent organizations, showcasing his commitment to knowledge dissemination. His expertise extends to long and short-term planning, project scheduling, and monitoring, with a focus on oil & gas, information technology, telecommunication and local government infrastructure planning using high-end planning tools. He has demonstrated pioneering efforts in advancing digital construction implementation throughout his planning career, leveraging cutting-edge methodologies such as Building Information Modelling-based- and 4D-planning to elevate project management standards and ensure optimal efficiency in complex engineering endeavours. He brings a wealth of experience in construction project management, consistently delivering successful outcomes through meticulous planning, coordination and client collaboration. He is well recognized in Construction Industry Development Board, Malaysia for his contribution in enhancing civil construction through the digital approach and adoption of visual technology.

María Fernanda Aguirre Bustos

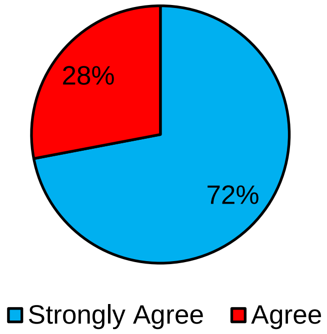
Ms. María Fernanda Aguirre Bustos is the Chief Executive Director of Chile Green Building Council, Chile, a board member of the World Green Building Council and an active participant in the financing, materials and sufficiency working groups of Global Alliance for Buildings and Construction under United Nations Environment Programme. She is an architect and an expert in sustainability applied to the built environment with multiple professional accreditations in certification systems. She possesses academic specializations in organizational sustainability, project management, responsible consumption and production, climate change and its implementation in publication policies. She has been working for more than 13 years, implementing sustainable development strategies in the construction sector, leading circular economy, decarbonization, adaptation, regeneration and resilience projects and participating in directories and public-private working groups at local, regional and international levels. She has also worked for six years as a Master’s Degree professor at University Metropolitan Technology of Chile.

Annex F: Responses of Workshop Evaluation

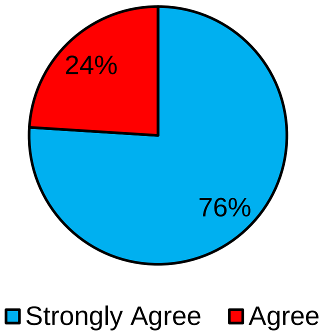
Discussion on application of products with recycled content in construction projects provided valuable insights for circular economy practices.



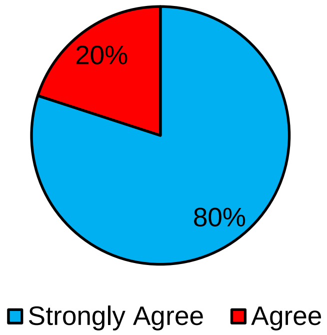
Discussion on recycling of municipal sewer sludge as construction material provided valuable insights for circular economy practices.



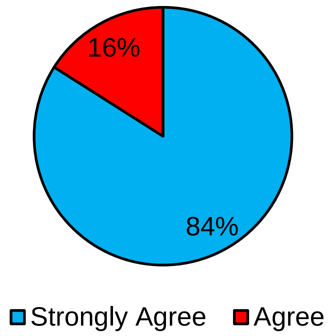
Discussion on adoption of digital construction for material optimization presented a crucial advancement for the construction industry.



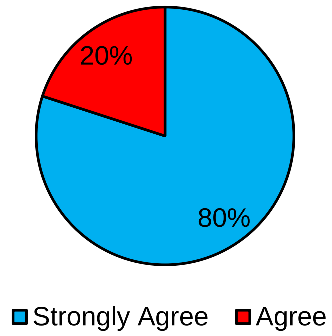
Discussion on state-of-the-art initiatives for the construction industry towards a circular economy was relevant to current industry trends.



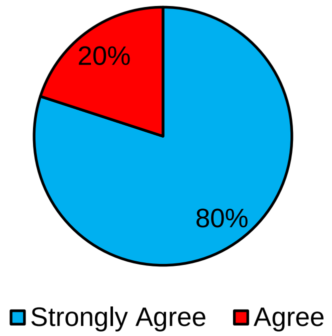
My knowledge on the implementation of circular economy principles in the construction industry has increased substantially.



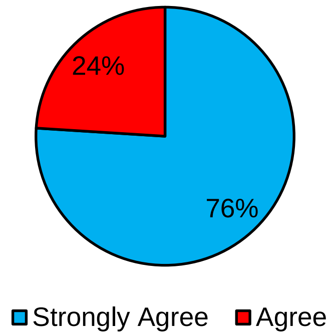
My understanding with regard to the industrial symbiosis approach for adoption of circular economy in the construction industry has improved substantially.



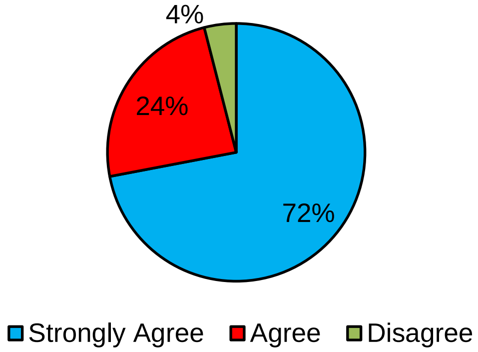
My knowledge on the management of construction and demolition waste for adoption of circular economy has increased substantially.



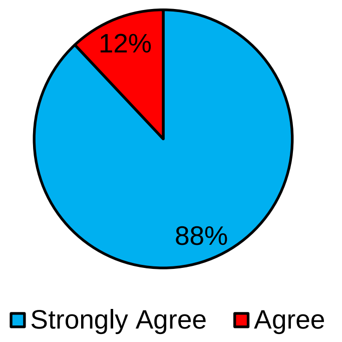
My knowledge on the reuse of municipal waste to produce construction material has increased substantially.



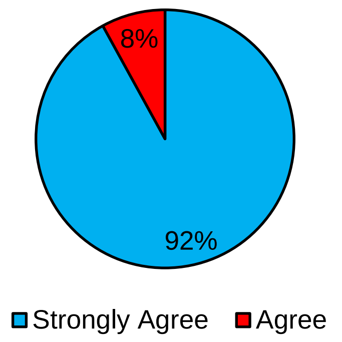
The session on digital construction has provided me with actionable insights that I can apply to my work.



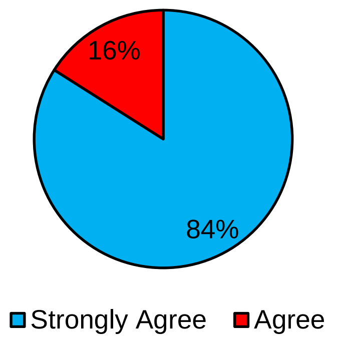
The workshop content was well-organized and delivered in an understandable manner.



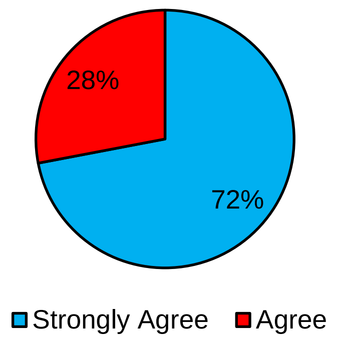
The choice of expert speakers for the workshop was appropriate and provided a diverse range of perspectives.



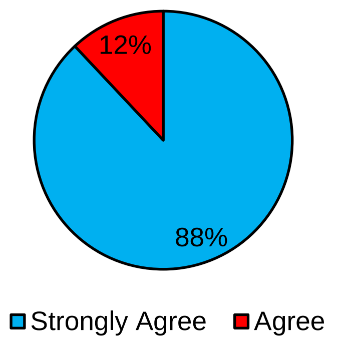
I am satisfied with the opportunity for networking and discussion provided during the workshop.



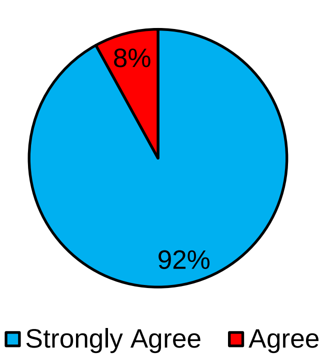
The workshop has motivated me to pursue specific actions that I can take to promote circular economy principles in my organization.



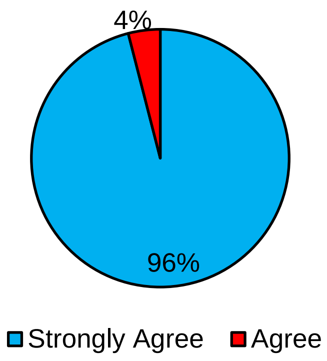
The workshop has allowed for equal opportunities for involvement and engagement for participation between both male and female speakers and participants.



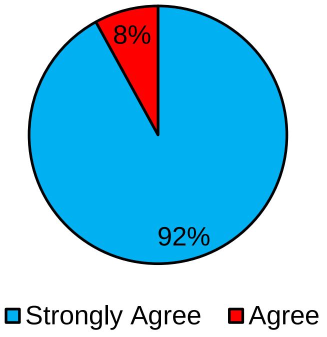
APEC should create more educational resources to promote circular economy in construction industry.



APEC can facilitate cross-border partnerships within the construction industry to advance circular economy practices.



APEC can facilitate to establish a platform for sharing best practices and technologies in circular economy among member economies.



I would like to see APEC take a leading role in standardising circular economy metrics and practices for the construction industry.