Global Impacts of Aluminium Flows from End-of-life Buildings in China

FINAL REPORT

June 2022

Authors: Wanjun Wang and Wei-Qiang Chen

Institute of Urban Environment,

Chinese Academy of Sciences

Table of Contents

List of Figures

List of Tables

Executive summary

China has been the largest aluminium producer and consumer worldwide for over ten years. As building is the main application for aluminium, aluminium stock in buildings accounts for more than 26% of the aluminium end-use in China, indicating that buildings could generate significant aluminium scrap. However, little research has been conducted on the current collection and recycling of aluminium scrap from buildings. This project aims to trace aluminium flows from end-of-life (EOL) buildings to recycling plants.

Interviews and field investigation were the main approaches. We surveyed demolition projects for both residential and commercial buildings in four big cities located in China's northern, western, eastern, and southern regions: Beijing, Xi'an, Shanghai, and Xiamen. To trace the collection and recycling route of aluminium scrap and collect information and data, several waste collection centres, aluminium scrap dealers, and aluminium recycling enterprises across China were surveyed.

From these investigations into demolition projects and recycling industries, we obtained information regarding (1) the main types of aluminium scrap generated from buildings, (2) aluminium content and collection rate of EOL buildings, (3) aluminium scrap collection network and recycling process, and (4) type and quantity of aluminium building scrap used by different recycling companies. Moreover, we identified challenges in China's demolition industry and aluminium recycling industry, which will be useful for improving aluminium scrap collection rates and help the development of the aluminium recycling industry.

Key findings are as follows:

- Since 1978, typical buildings in China have been subjected to perpetual development, owing to the great development of construction and design techniques and materials. All types of buildings have become taller and better designed, which has increased the average aluminium content in Chinese buildings.
- Residential and commercial buildings built before the 1980s are more likely to be demolished in China than other buildings. They are mainly brick-wood and brick-concrete buildings with less than six floors. Aside from those buildings, illegally constructed buildings of any age and

application have the highest chance of being demolished, especially in cities where land is limited.

- Aluminium frames and plates for windows, doors, and curtain walls are the most likely to be used in China's EOL buildings, which are currently the most available source for possible scrap to recycle.
- Based on the demolition project surveys for residential and commercial buildings, aluminium-containing building parts in Chinese EOL buildings are aluminium window and door frames and aluminium-plastic boards used for external walls. Both are wrought alloys. The application of aluminium containing building parts is influenced by factors such as design year, income, climate, and building purpose.
- The aluminium content in residential buildings in China has a wider range than that of commercial buildings. Compared with European buildings, Chinese residential and commercial buildings have less aluminium content than those in European countries, respectively.

Building Type	**Location**	**Aluminium share (g/t)**	**Collection rate (%)**
Residential building	**Beijing: bungalow**	**26**	**100**
	Beijing: five-story building	**52**	**100**
	Xiamen: three-story building	**753**	**100**
	France	18	31
	The Netherlands	32	95
	The Netherlands	49	95
Commercial building	**Beijing: Tongzhou**	**118**	**96**
	Beijing: Shunyi	**379**	**16**
	Xi'an: B1-21	**94**	**100**
	Xi'an: B5-5	**202**	**100**
	Xi'an: B8-30	**238**	**100**
	Shanghai: Baoshan Hotel	**374**	**100**
	France	640	92
	Germany	7500	98
	Germany	1750	98
	Italy	430	94
	Spain	4000	95
	The United Kingdom	6100	96

- In this project, only aluminium window and door frames had been collected. Aluminium-plastic boards were not collected at either the demolition sites or construction and demolition waste (C&DW) recycling plants. With the development of C&DW recycling plants in an increasing number of Chinese cities, aluminium scrap not collected at demolition sites can be sorted and collected at C&DW recycling plants, which will increase the overall aluminium scrap collection rate.
- Aluminium scrap can mainly be divided into two groups in the scrap market: casting scrap and wrought scrap. Wrought scrap includes old kitchenware (1XXX/3XXX), waste aluminium cans (3XXX/5XXX), scrap wire (1XXX), old printing plates (1XXX), old sheets, old roller doors, old frames (6XXX), and other old extrusions. Casting scrap includes old bicycles, motorcycles, car wheels, old pistons, old radiator tanks, old engines, and other aluminium scrap from machines.
- For a long time, aluminium-plastic boards were sent to landfills or incineration plants instead of being recycled. However, owing to a recently developed type of separating machine that can divide such material into aluminium plates and plastic plates, a few aluminium dealers have begun to collect aluminium-plastic boards.
- Before being refined, aluminium scrap, such as aluminium frame scrap and old wires, is separated from impurities, such as steel and wood, by metal dealers and recycling plants.
- Different recycling companies have very similar production processes for each secondary aluminium alloy. Production processes of casting alloys and wrought alloys have little differences. A purification system is needed for wrought alloy production.
- Aluminium frame scrap, which was the only type of aluminium-containing building parts collected during the surveys, is mainly used to produce extrusion billets. However, it can be used for casting alloy production. Based on the on-site surveys, producing 1 t secondary extrusion billets in China will use 0.75~0.95 t of aluminium frame scrap, while producing 1 t of casting ingots may use 0~0.15 t aluminium frame scrap.
- Recycling enterprises seldom use casting scrap to produce wrought alloys, although wrought

scrap is still used for secondary casting alloy production. However, the proportion of secondary wrought scrap is not very large, because producing casting alloys using wrought scrap and producing wrought alloys using casting scrap are not cost-effective and may result in low-quality products and reduce the profitability of aluminium recycling enterprises.

- The aluminium recycling industry in China has reached a higher level than that shown in previous studies. However, it still urgent to improve efforts to build a closed loop for aluminium recycling in China and efficiently utilise wrought scrap.

1. Introduction

Aluminium is the most used non-ferrous metal worldwide, and is indispensable for economic growth, industrialisation, and urbanisation. Global demand for aluminium is expanding, especially in China. China has been the largest aluminium producer and consumer worldwide for over 10 years. In 2019, China produced 48.7 Mt of aluminium ingots, accounting for nearly 50% of global production[1]. However, as China is not rich in bauxite, high production and consumption have led to high dependence on foreign raw resources. Furthermore, primary aluminium production is extremely energy and emissions intensive, which is preventing China and the world from becoming carbon neutral[2].

Secondary aluminium production expends approximately 95% less energy than does primary production and helps reduce the volume of raw resources required. Studies have shown that secondary aluminium will become the main source of aluminium resources in China, and if all aluminium scrap is fully recycled, national demand can be fully met by secondary aluminium after 2050[3]. Therefore, it is necessary to analyse aluminium recycling in China.

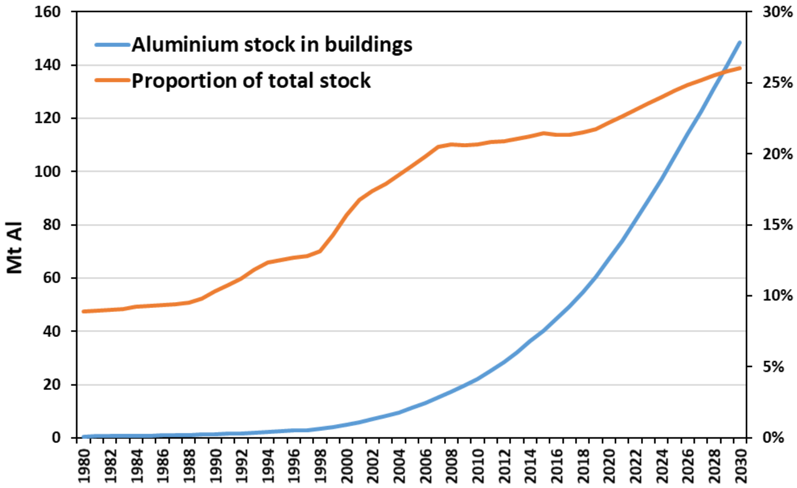

Figure 1-1 Aluminium stock in Chinese buildings from 1980 to 2030.

Data source: IAI, https://alucycle.world-aluminium.org/public-access/

Aluminium is mainly used in building construction[4]. Owing to its properties such as formability, functionality, flexibility, lightweight nature, excellent recyclability, and corrosion resistance, aluminium is a good replacement of steel or copper, and is used for a wide range of applications in buildings, especially for maintenance-free applications such as siding, windows, skylights, doors, screens, gutters, down spouts, hardware, canopies, and shingles[5]. China is still experiencing a rapid urbanisation process; thus, the country's stock of buildings will continue to rise, which also lead to the increase of aluminium stock in these buildings[1]. By 2030, aluminium stock in Chinese buildings is predicted to reach 150 Mt, which is approximately 26% of the total end-use aluminium in China (Figure 1-1). Thus, the building sector has considerable aluminium scrap potential, and buildings are an important source of aluminium. Accordingly, it is necessary to research the aluminium scrap potential of – and recycle all scrap from – end-of-life (EOL) buildings.

However, to date, few on-site investigations regarding the types and quantities of aluminium scrap generated from EOL buildings in China have been conducted, although some studies have been conducted in Europe[6,7], Japan[8], and the US[9]. Research shows that aluminium scrap generation varies greatly between buildings[6], owing to differences in construction and design techniques, work procedures, and common practices[10]. Countries differ in their mainstream building styles; therefore, construction and design techniques vary internationally. For example, individual houses are the main residential buildings in much of Europe and the US, while apartments are more common in China. Furthermore, although wood is still an important construction material in Europe and the US, the height of many Chinese building leads to the more prevalent use of concrete in construction. Thus, the aluminium content of buildings varies greatly among different countries. However, a lack of data regarding the aluminium content of Chinese buildings has made it difficult to accurately estimate the quantity of different types of aluminium scrap in the Chinese building sector or formulate plans to improve recycling rates.

Research is also scarce regarding the current situation of aluminium scrap collection, especially for that from buildings. Most previous studies were conducted prior to 2010, and information and data regarding China's aluminium collection and recycling system is mainly based on expert and practitioner experience. Thus, updated information and data are urgently needed.

To fill these research gaps, this project aims to comprehensively track the generation, collection, and recycling of aluminium scrap from EOL buildings in China and provide information and data to support aluminium scrap recycling.

2. Methodology

2.1 Research plan

The research plan is shown in Figure 2-1, and comprises three main research tasks. First, to build an initial material flow model, we conducted a literature review and expert interviews on three research topics: building type and material use, demolition waste generation and recycling, and aluminium collection and recycling. Second, we selected cities in which to collect basic information on EOL buildings, such as such as building structure, lifespan, height, building area, floor space, and material use. We then identified and recorded the types and quantities of aluminium scrap generated from Chinese EOL buildings in the selected cities and the total amount of demolition waste. Third, we collected information regarding the aluminium scrap collection and recycling processes, including aluminium scrap classification, sorting techniques, and refining techniques; recorded quantities in relation to aluminium recycling flow from secondary aluminium ingots to semi-products, such as rolled, extruded, and casting products; and collected data and information on quantity, aluminium content, source, and whereabouts of each aluminium scrap type.

Owing to regional differences in building structures and appearance preferences, we selected four cities, located in northern, western, eastern, and southern China: Beijing, Xi’an, Shanghai, and Xiamen. In principle, we aimed to select two buildings in each city (i.e., one residential and one non-residential); however, considering the risk of failing to obtain data, nine buildings have been chosen.

2.2 Research approaches

Interviews and field investigation were the main research approaches used in the present study. We interviewed professionals and practitioners in the demolition, waste collection, and aluminium recycling industries to collect information such as industry status, procedures, and basic specifications. To quantify aluminium scrap generation and demolition waste and calculate collection rates, we conducted interviews and field investigations, such as site observations, on-site sorting, weighing aluminium scrap, and monitoring related records. Aluminium building parts can be removed by owners and rag pickers before the buildings are demolished; therefore, to identify all building parts that contain aluminium, field investigations began prior to building demolition and continued until the end of the demolition to obtain the total quantity of waste generated at these sites. As demolition companies cannot to record data on the aluminium scrap that has not been removed and collected, we collected samples to estimate the quantity and compile data.

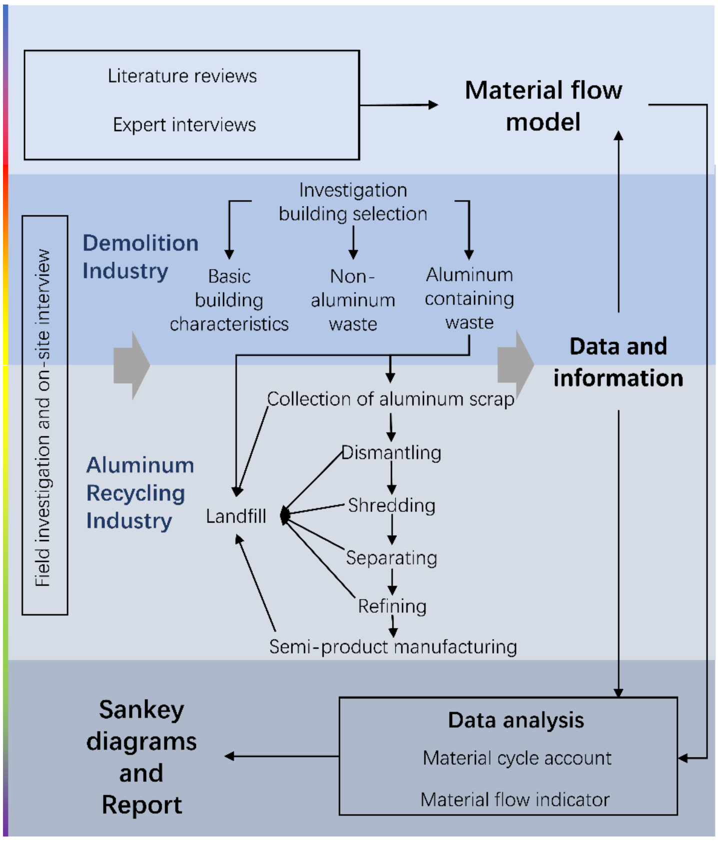

Figure 2-1 Project structure.

3. Background: history of aluminium use in Chinese buildings

3.1 Development of Chinese buildings

Since 1978, China has experienced tremendous economic and social changes, including the great development of construction techniques and materials. Depending on their occupancy or use characteristics, buildings can be categorised into five types: residential, commercial, industrial, public, and infrastructure. Figure 3-1 shows examples of each building type by decade from the 1970s to the present. All types of Chinese buildings have become higher, larger, and more attractive over time, with improvements in construction and design techniques. In China, residential and commercial are the main building types, accounting for approximately 90% of the total building stock. Thus, we will focus on these two types of buildings to provide further analysis.

3.1.1 History of residential buildings

China has both non-commercial and commercial residential buildings (Figure 3-2). Non-commercial residential buildings are built by the property owner, while commercial residential buildings are built by real estate companies.

China's real estate market opened in 1980, when the first commercial residential community was built in Shenzhen. Prior to that, all residential buildings in China were non-commercial residential buildings, which were built by individual owners in rural areas or national enterprises and public institutions in urban areas. From 1980 to 1998, new buildings were still mainly non-commercial residential buildings. However, after 1998, commercial residential buildings became the mainstream residential buildings.

Figure 3-1 Pictures of example buildings for each building category from 1970 to 2020.

Figure 3-2 Typical residential buildings in urban and rural area from 1950 to 2020.

According to the structure and materials, there are four types of residential buildings in China: wood, brick-wood, brick-concrete, and reinforced-concrete houses. Prior to the 1900s, wood buildings were the main type of buildings. However, nearly all of them have been demolished. Among the existing buildings in China, most brick-wood houses were constructed in both urban and rural areas before the 1960s, were built by families and individuals, and generally have only one or two storeys. Following the 1960s, brick-concrete houses have been increasingly built in urban areas. From 1960 to 1980, new buildings in urban areas were usually worker dormitories provided by the government and national companies, and normally had less than five storeys. However. in rural areas, owing to a lack of investments, buildings did not change much during this period, and brick-wood houses are still the main type of rural buildings.

After 1980, urban people increasingly lived in commercial residential communities, which mostly comprised six to seven story brick-concrete buildings. After 2000, rapid urbanisation and rising land prices led to real estate companies preferring to construct high-rise buildings. Most new buildings after that time have been constructed using reinforced concrete, with an increasing number of floors. At the same time, self-built residential buildings in villages surrounded by urban areas, which are called urban villages, are more likely to be reinforced-concrete houses with more floors, especially in big cities. This is because there are huge nonlocal populations in urban areas. The higher the building, the more residential units the property owner can rent out. After 2010, high-rise commercial residential buildings with over ten floors became popular in urban areas.

In rural areas, with the development of construction technology and increasing incomes among residents, families and individuals have increasingly built reinforced-concrete houses in rural areas.

3.1.2 History of commercial buildings

Before 1978, hotel and office buildings were brick-concrete buildings with fewer than six floors. Nearly all were built by the government or national companies, and at that time, there were no obvious differences between residential and commercial buildings in China. With economic development and high resident income growth, shopping malls were increasingly built after the 1980s. The first commercial office buildings were also built at that time and were generally reinforced-concrete buildings with more than ten floors. Over time, supermarkets, shopping malls, and shopping centres successively appeared.

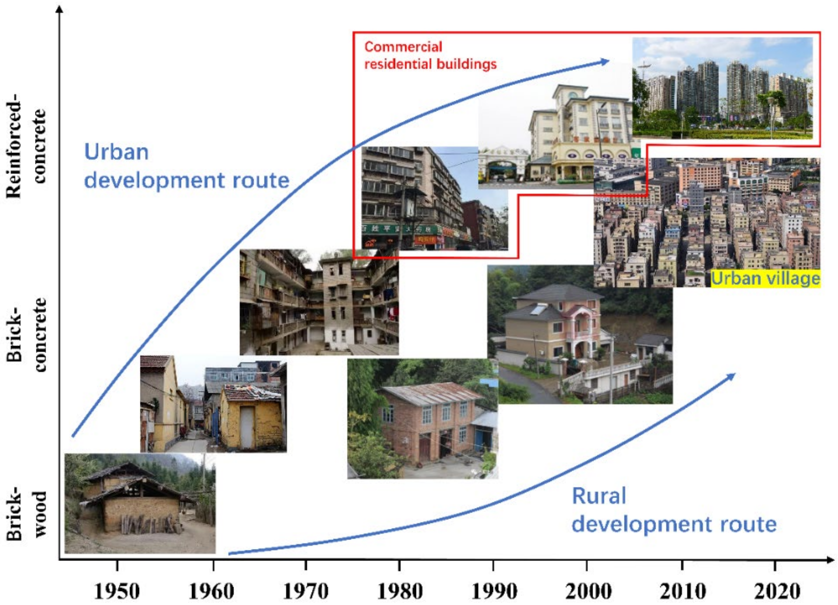

Figure 3-3 Typical street-side residential buildings in China.

Compared with residential buildings constructed during the same period, these shopping centres, hotels, and office buildings were bigger, higher, and better designed. This is because new construction and design techniques are commonly first applied to commercial buildings. For example, glass curtain walls were first used in commercial buildings. Hence, commercial buildings usually have more complex structures and designs than residential buildings constructed during the same period.

However, shopping centres are not the most common retail areas in China. Street-side residential buildings have both residential and commercial spaces, with small shops on the first floor, and the upper floors used for dwellings (Figure 3-3). Even for commercial residential buildings, real estate companies will build shops around residential buildings. These countless small shops are the most common type of retail space in China.

3.1.3 Characteristics of EOL buildings

Economic development and population growth are the main forces driving building demolitions because they can increase land prices. The higher the land price, the easier it is to demolish and upgrade the buildings on that land. Therefore, compared with maintaining old buildings, demolitions can provide greater economic and social benefits.

Whether residential and commercial buildings will be demolished is mainly determined by the buildings' characteristics and location. First, regarding construction date, the earlier a building was constructed, the higher the possibility it will be demolished, because older buildings have higher degrees of depreciation, are more difficult to repair, and have higher maintenance cost. Second, the fewer floors a building has, the higher the possibility it will be demolished, because lower buildings have lower demolition compensation costs. Third, the durability of building materials is considered, as wood, brick-wood, and brick-concrete buildings are generally easier to demolish than reinforced-concrete ones. Fourth, individual buildings are much easier to demolish than residential communities. Fifth, buildings closer to commercial centres are more likely to be demolished, because governments need to improve the function and image of commercial areas. In addition, any illegal buildings, regardless of construction date or conditions, will be demolished, especially in cities where land is limited.

Thus, buildings in China that have a high probability of being demolished are mainly residential and commercial buildings built before 1980. These are mostly brick-wood or brick-concrete buildings with fewer than six floors.

3.2 History of aluminium use in Chinese buildings

Architectural design is the expression of people's personality and wealth. Economic shifts and changes in aesthetic, design techniques, and materials have also led to continued architectural development over time. Owing to the various useful properties of aluminium, it began to be used in Chinese buildings in the 1970s. Improvements in aluminium fabrication technologies and increased aluminium production capability have caused aluminium prices to continue to fall, resulting in the expansion of aluminium application in Chinese buildings. The types of building parts that contain aluminium are increasing, and the use of these parts is also gradually spreading from commercial to residential buildings.

3.2.1 Inventory of aluminium use in buildings

Aluminium can be found mainly in window and doors, ceilings, internal and external walls, sun shading systems, burglar bars, and fences. For commercial buildings, aluminium is also found in curtain walls and roofs (Figure 3-4). The same building parts may use different types of aluminium alloys, depending on the design techniques. For example, ceilings can be covered by aluminium plates (rolling) or plastic plates with aluminium joists (extrusion).

Figure 3-4 Typical aluminium applications in Chinese buildings.

Based on aluminium fabricating techniques, aluminium-containing building parts can be divided into three groups (Figure 3-5). The most common is extrusion (mainly 6XXX series), including aluminium window and door frames, curtain wall frames, ceiling joists, and sun-shading frames. This group accounted for 86% of total the aluminium consumption in buildings in 2014. The second group comprises rolled products (mainly 3XXX, 5XXX series), and made up 12% of the total aluminium consumption in buildings in 2014. The main building parts in this group are aluminium plates such as those used in internal and external walls, ceilings, sunshades, and roofs. Recently, some new aluminium composite materials have been developed, such as aluminium-plastic composites, aluminium foam composites, and aluminium honeycomb panels. The third group comprises aluminium casting products, including aluminium sinks and hardware fittings. This group is the smallest in terms of having both the fewest types of parts and the lowest consumption proportion, which was only 2% in 2014.

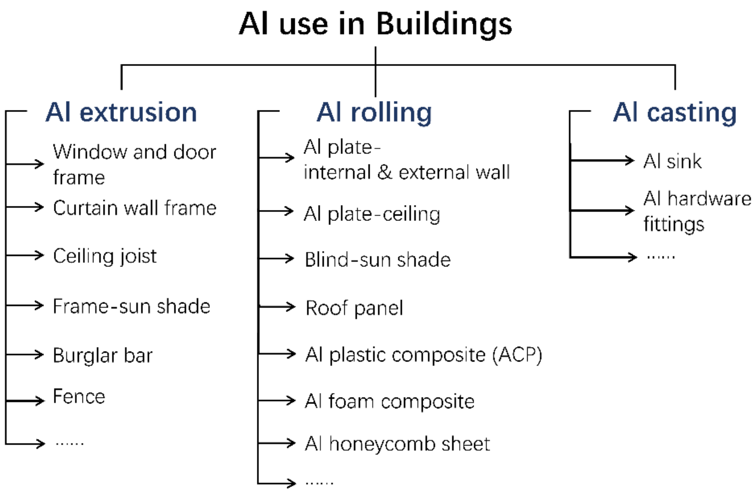

Figure 3-5 Types of aluminium-containing building parts.

3.2.2 Evolution of typical aluminium use in buildings

Table 3-1 shows the development history of aluminium-containing building parts. Aluminium windows and doors were the first aluminium-containing building parts introduced in China and are still the most widely used aluminium-containing building parts in China today. The first building that used aluminium windows and doors was a commercial building constructed in 1980, for which all the aluminium windows and doors were imported. In 1982, China developed the capability to produce aluminium windows and doors, which began to be applied in residential buildings around the same time. After the 2000s, as the government began to place greater focus on energy efficiency, broken bridge aluminium windows and doors were applied in China's residential and commercial buildings. In 2012, approximately 67% of all windows and doors constructed included aluminium, and this proportion is still increasing.

The second most common type of aluminium-containing building parts are curtain walls, which have also been applied in China since the 1980s. The Beijing Great Wall Hotel was the first building in China to use curtain walls, which were composed of glass and aluminium frames. After the 1990s, curtain walls became popular in China's commercial buildings, with increasing types of curtain walls introduced in China, including aluminium panel curtain walls. However, until the 2010s, curtain walls were not applied in residential buildings. Aluminium-containing curtain walls accounted for one-third of the total curtain wall consumption.

Ceilings are another main building part that often contain aluminium. Aluminium-containing ceilings were first applied in China in the 1990s, when they were first used in commercial buildings, and have become a common design material in both commercial and residential buildings. Plastic boards with aluminium joists are the most common type of ceiling in China because of their low cost. Aluminium plate ceilings have a better appearance and are the second most popular in China; however, because they have a much higher price, aluminium plate ceilings are mostly used in commercial buildings. Internal and external aluminium plates are very similar to aluminium plate ceilings and have been applied mainly in commercial buildings in China since the 1990s.

Aluminium-containing sunshades, such as venetian blinds, roller shutters, and sun shields, have only stated to be used in Chinese buildings recently. Therefore, these comprise the lowest proportion of aluminium consumption in buildings. In addition, most are used in commercial buildings.

From the above in China, aluminium was first used in windows and doors. Then, the application of aluminium was expanded into internal and external walls, ceilings, and roofs. Almost all aluminium building parts were first used in commercial buildings, and then in residential buildings. Moreover, buildings constructed before the 1980s have been the most likely to be demolished in recent years; thus, aluminium window and door frames and aluminium-containing curtain walls should be the most common aluminium-containing building parts removed currently.

Table 3-1 The development history of aluminium-containing building parts.

Al containing building parts	1970s	1980s	1990s	2000s	2010s
Residential Buildings	Hardly any	●Windows and doors	●Windows and doors	●Windows and doors (including broken bridge) ●Ceilings	●Windows and doors (including broken bridge) ●Ceilings ●Curtain walls
Commercial Buildings	Hardly any	●Windows and doors ●Curtain walls	●Windows and doors ●Ceilings ●Curtain walls ●Internal and external walls	●Windows and doors (including broken bridge) ●Ceilings ●Curtain walls ●Internal and external walls	●Windows and doors (including broken bridge) ●Ceilings ●Curtain walls ●Internal and external walls ●Sunshades

4. Material flow model of aluminium scrap from Chinese EOL buildings

The goal of this study is to assess the aluminium flow from Chinese EOL buildings. Therefore, all the processes from aluminium scrap generation to the collection and recycling phases should be studied. Based on a literature review and on-site investigations and interviews, a simple framework of aluminium flow from Chinese EOL buildings is shown in Figure 4-1. There are four processes: scrap generation, collection process 1, collection process 2, and recycling process.

4.1 Framework of aluminium flow from Chinese EOL buildings

Aluminium is mostly used as a decorate material; thus, most aluminium-containing parts are used in the accessory structure of buildings. These building parts will be removed and collected during accessory structure demolition. Then, this aluminium scrap will be sold to a metal scrap dealer or collection centre. After a few hours or days of storage, this aluminium scrap will be sold to a refiner or remelter.

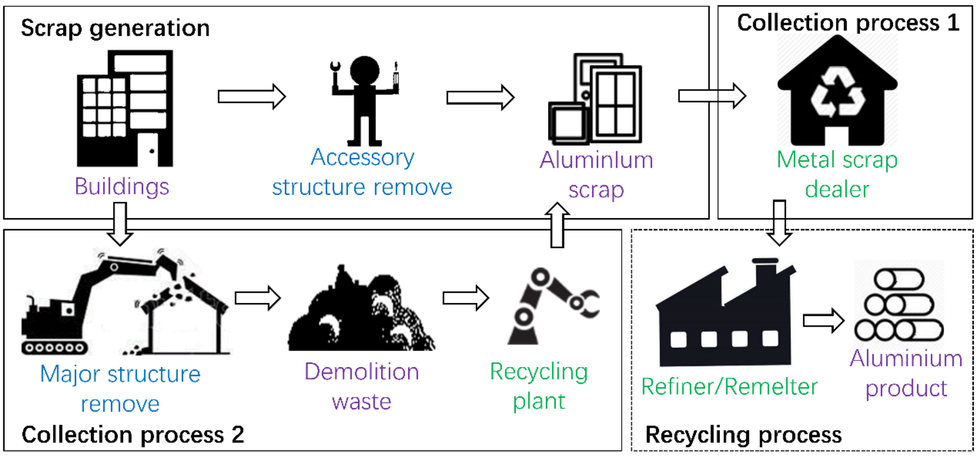

Figure 4-1 Life cycle of aluminium scrap from Chinese EOL buildings.

After removing the accessory structure, the major structure is demolished. The major structure of a building does not contain aluminium parts; however, aluminium-containing building parts that were not collected during the accessory structure demolition process will be mixed with other demolition waste. Construction and waste demolition (C&DW) recycling plants have been set up in some Chinese cities. In these cities, all demolition waste should be sent to these C&DW recycling plants, where demolition waste is sorted, and aluminium-containing building parts can be picked out. The aluminium scrap will be also sold to metal scrap dealers, and then sent to refiners or remelters to produce aluminium semi-finished products.

4.1.1 Demolition procedure

Aluminium scrap is generated during building demolition. There are two kinds of demolition procedures: demolition requested by owners with independent property rights, and those initiated by the government for urban development or public need. Figure 4-2 shows a normal demolition procedure in China. First, owners or relevant government departments should submit application for demolition. After the application is approved, an open tender will be held, and a demolition company will be determined. The demolition company should receive all the necessary information about the building and perform and on-site inspection to create a demolition plan. The company should perform all the site cleaning and all the preparatory work and wait for the demolition date set by the local governments. These three steps may take over a year to complete.

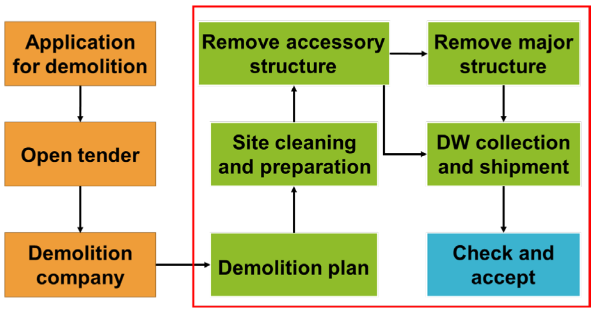

Figure 4-2 Building demolition procedure in China.

Several days before the demolition, the company will first remove the accessory structure, including all valuable parts, such as the windows and doors, wire, radiators, and metal stairs. Nearly all the aluminium will be removed from the major structure, which is made by reinforced concrete, during this time. The company will collect and sell these valuable items to different scrap dealers. Then, the major structure will be removed. These processes may take two days or up to one week.

A common demolition project includes more than one building; therefore, the above demolition steps (red square) will be repeated several times. Thus, a demolition project usually last for two to three months. During this time, generally no one is residing in these EOL buildings, which provides rag pickers with a chance to collect some valuable items, including aluminium scrap. The building owner may also remove and sell the scrap metal.

4.1.2 Aluminium scrap collection and recycling processes

After aluminium scrap has been collected at demolition sites or a C&DW recycling plant, it will be sold to collection centres (yellow circle) or metal scrap dealers (grey circle) of various sizes (Figure 4-3). The collection network could be very complex. During the collection phase, mixed scrap will be separate into different groups based on scrap characteristics. Large obstacle aluminium containing building parts will be torn down into fragments and further sorted. All aluminium scrap from EOL buildings will be combined with that from other sources and be sent to recycling plants (Figure 4-4). In recycling phase, aluminium scrap will undergo four main processes: pre-processing, remelting, composition adjusting, and refining. All aluminium scrap will be made into secondary aluminium and further processed into various semi-finished products though different production processes.

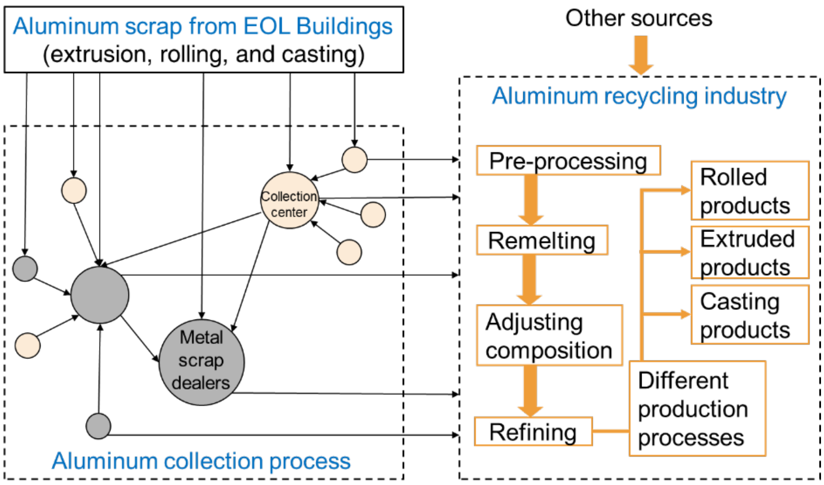

Figure 4-3 Aluminium flow from EOL buildings in China.

The ideal recycling system is a closed product loop[11], which means that extruded, rolled, and casting scrap are used to produce the same aluminium products. In Europe, mixed scrap is generally divided into two groups and undergoes two different processes: refining and remelting[12]. The former produces casting alloys, and the latter produces wrought alloys, including extruded and rolled alloys. However, based on previous studies, owing to the presence of impurities in and mixed use of aluminium scrap, most aluminium scrap in China is used to produce casting alloys.

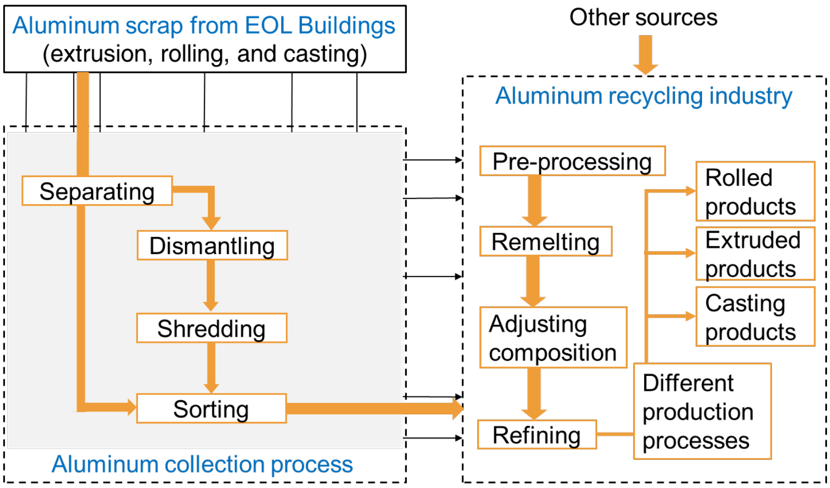

Figure 4-4 Framework of aluminium flow from EOL buildings in China.

5. Aluminium scrap generation: surveys of EOL buildings

We conducted surveys on demolished buildings in Beijing, Xi'an, Shanghai, and Xiamen from 2018 to 2019. In Beijing, we surveyed three demolition projects, including several self-built residential bungalows (most of them were for both residential and commercial use), one five-story commercial residential building, one self-built illegal building for commercial use, and one public building (hospital). In Xi'an, we surveyed the biggest demolition project for a famous urban village in this city. Three mixed-use buildings in this urban village with more than six floors were surveyed. In Shanghai, a refurbishing project for a four-star hotel was surveyed. A three-story self-built residential house was surveyed in Xiamen. All the buildings are listed in Figure 5-1. More detailed information and data are as follows.

Figure 5-1 List of buildings surveyed in Beijing, Xi'an, Shanghai, and Xiamen.

5.1 Beijing

Beijing is a typical large city in China's northern region. We chose it as the representative of northern cities, and investigated residential, commercial, and public buildings in three demolition projects.

5.1.1 EOL residential buildings

We surveyed EOL residential buildings located in the Wangtan community in Beijing's Dongcheng district. As shown in a 3D map (Figure 5-2), residential buildings in this community were bungalows and buildings with two to six storeys, which were surrounded by high-rises and modern buildings. In 2017, the local government planned to transform it into a new residential community, and the demolition project began in early 2018.

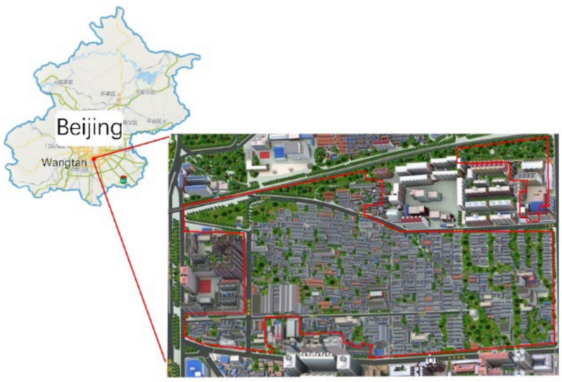

Figure 5-2 Location and 3D map of the Wangtan community.

The Wangtan community covered an area of 47 hectares, and the floor area of the residential buildings was 280,000 m^2. There were 5700 families living there, including 4700 families living in bungalows. These bungalows were mainly built after the 1950s. After several renovations and construction of extensions, most of the buildings were brick-wood or brick-concrete houses with less than three storeys. This community also had 90 commercial residential buildings with two to six storeys, which were constructed in the 1980s and housed approximately 1000 families. They were brick-concrete buildings; however, in 2013, some had reinforced concrete added.

Bungalows may share walls; therefore, demolition companies usually tear down several bungalows at one time, making it difficult to collect data on one bungalow. We chose 300 bungalows as samples, measured the size of aluminium building parts in them, and collected data on the weight of aluminium scrap and demolition waste. We also collected information and data for one five-story commercial residential building that was demolished during the survey period.

As Figure 5-3 shows, aluminium window and door frames were the only aluminium-containing building parts found in the five-story building and 300 bungalows. In the five-story building, aluminium windows were only found on the balconies. Considering construction costs, commercial residential buildings built before the 2000s often used plastic-steel windows. Residents may have used aluminium frames to decorate the balconies. Among the bungalow, 11 buildings used aluminium windows and doors. All windows and doors in these buildings were made using aluminium alloy, because these buildings were built by the property owners themselves, and they tended to use the same type of windows.

Figure 5-3 Aluminium building parts in demolished residential buildings in the Wangtan community.

All the aluminium window and door frames were removed and collected by a collection centre. The total quantities of scrap from the bungalows and five-story building were 0.7 t and 0.12 t, respectively. The bungalows' aluminium share was 26 g/t, while that of the five-story building was 52 g/t. Collection rates for both were 100% (Table 5-1).

Table 5-1 Demolition data on the Wangtan investigation.

Wangtan Project	**Bungalows**	**Per Bungalow**	**Five-story building (NO. 19 on 3rd Guozhuang Street)**
Floor area (m^2)	21,000	70	1,680
Al (t)	0.7	0.0023	0.12
Mass of building (t)	27,000	90	2,300
Al share (g/t)	26	26	52
Collection rate (%)	100%	100%	100%

5.1.2 EOL commercial buildings

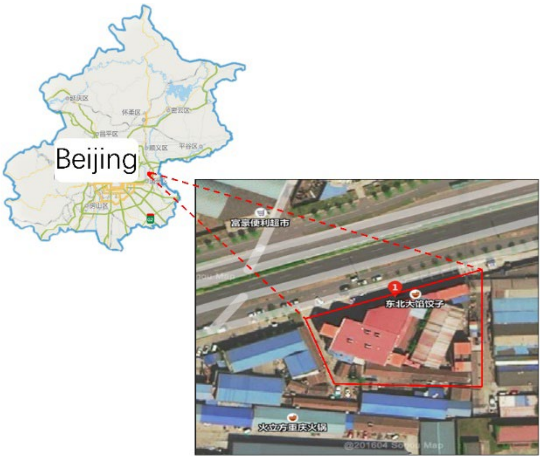

Figure 5-4 The location and satellite map of Tongzhou's demolished commercial building.

In 2017, Beijing launched a special rectification project to dismantle illegal constructions. In the Tongzhou district, Yongshun town, 1,400,000 m^2 of illegal commercial buildings were to be demolished in the second half of 2018. The demolished building that we surveyed was in this town (Figure 5-4). This commercial building was built in 2010, with a floor area of 5200 m^2. A small hotel, dumpling restaurant, and used car dealership were in this reinforced-concrete building.

Figure 5-5 Aluminium building parts in the demolished commercial buildings of the Tongzhou district.

As shown in Figure 5-5, there were two types of aluminium-containing building parts in this commercial building: aluminium window frames and aluminium-plastic boards. Aluminium windows were in the dumpling restaurant's lobby and garage of the used car dealership. The wall facing the street of the first floor had been covered by aluminium-plastic boards. During the entire demolition and collection processes, all the aluminium window frames were collected and sold to a metal scrap dealer. The amount of aluminium window frame scrap totalled 482 kg. However, they did not collect the aluminium-plastic boards had a low aluminium content and were not collected during the demolition process. These aluminium-plastic boards were sent to the recycling plant with other demolition waste; therefore, we could not record the actual volume on-site. Fortunately, we were able to obtain a sample to estimate the aluminium content of the boards (126g/m^2), and we also measured the surface area they had covered (about 150 m^2). There were 18.9 kg of aluminium that were not collected.

As Table 5-2 shows, the total aluminium scrap generated from this commercial building was 0.5t. The aluminium share was 123 g/t, which was higher than that in the Wangtan project. The collection rate was 96%.

Table 5-2 Demolition data on the Tongzhou investigation.

Tongzhou Project	Quantity
Floor area (m^2)	5,200
Al (t)	0.5
Mass of building (t)	4,056
Al share (g/t)	123
Collection rate (%)	96%

5.1.3 EOL public buildings

The maternal and child health hospital of the Shunyi district was demolished in the second half of 2018 (Figure 5-6). The hospital complex included three buildings, which were built in 1995 and refurbished in 2015 by local government. The floor area was 2,900 m^2 and covered an area of 1,800 m^2. Building 1, which was the main building, was a reinforced-concrete structure with three floors. Buildings 2 and 3 each had only one floor and were brick-concrete structures.

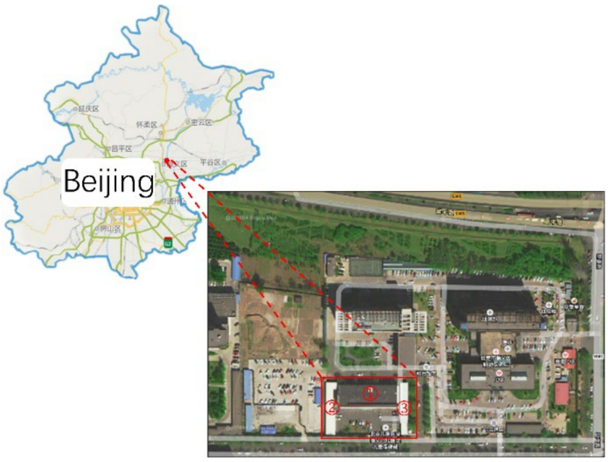

Figure 5-6 The location and satellite map of Shunyi's demolished commercial buildings.

Aluminium window frames and aluminium-plastic boards were the aluminium-containing building parts in the three hospital buildings. In Building 1, the windows were all broken bridge aluminium windows, and its three facades were covered by aluminium-plastic boards. However, Buildings 2 and 3 did not contain any aluminium building parts. Aluminium window frames moved from building 1 (165 kg) had been collected and sold to a scrap metal dealer. Like the Yongshun project, the aluminium-plastic boards in this project were not collected at the demolition site. We also obtained a sample before demolition, to estimate the aluminium content of these aluminium-plastic boards (0.8 kg/m2) and measured the surface area covered by aluminium-plastic boards (approximately 1120 m2). In total, 896 kg of aluminium in the aluminium plastic-boards was not collected.

Figure 5-7 Aluminium building parts in the demolished commercial buildings of the Shunyi district.

The aluminium share of this project was 379 g/t, which was the highest compared with the other commercial buildings. This is because these were public buildings that had been refurbished in 2015. They were decorated by better aluminium building parts. However, because the aluminium-plastic boards were not collected, the collection rate was only 16%, which was the lowest among all the buildings surveyed.

Table 5-3 Demolition data on the Shunyi investigation.

Shunyi Project	Quantity
Floor area (m^2)	2,900
Al (t)	1
Mass of building (t)	2,639
Al share (g/t)	379
Collection rate (%)	16%

5.2 Xi'an

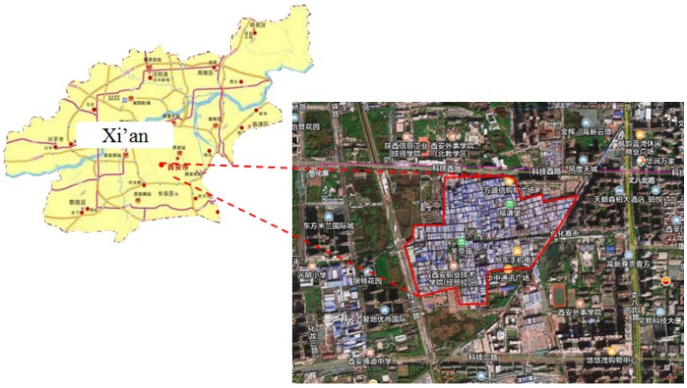

Figure 5-8 The location and satellite map of Yuhuazhai village.

We chose Xi'an, the door to China's northwest, as the representative of northwest cities. In this city, we investigated the Yuhuazhai demolition project, which was the largest demolition project in Xi'an in 2019 (Figure 5-8).

Yuhuazhai was previously one of the biggest urban villages in Xi'an, with an area of 66.7 hectares. It was adjacent to universities and only 7 km away from the city centre. Owing to its good location and low rental rates, this area had great commercial vitality and attracts migrant workers and college graduate. It had a large population of over 300,000 people. To support such a big population on a limited amount of land, this urban village experienced has undergone several upgrades and renovations, and almost all the buildings in this area were made of reinforced concrete, with six to eight storeys. The buildings were dense, and the roads were narrow. Aside from the rooms where the villagers lived, all other rooms were rented out as accommodations, restaurants, and small shops.

Therefore, all the buildings in this urban village were used for both residential and commercial purposes. However, as this area was crowded and chaotic, in October 2018, the government decided this area should be demolished in early 2019.

This area had more than 1000 buildings. We selected three buildings (B1-21, B5-5, B8-30) as samples, detected the types of aluminium building parts, and collected data on the weight of aluminium scrap and C&DW.

5.2.1 Mix used building: B1-21

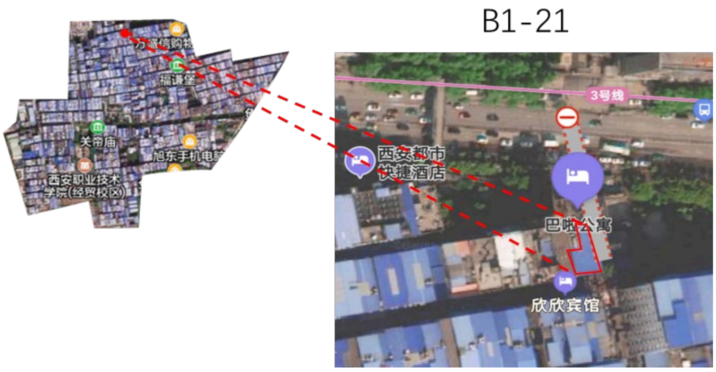

Figure 5-9 The location and satellite map of B1-21.

Figure 5-10 Aluminium building parts from B1-21.

B1-21 was a reinforced-concrete commercial building with a floor area of 1,405 m^2 and included an Internet cafe and rental apartments. The landlord lived on the first and second floors, and the rest of the floors were rented. As shown in Figure 5-10, aluminium windows and doors were the only aluminium-containing building parts in this six-story building. In total, 0.19 t aluminium scrap was collected and sold by a collection centre. The aluminium share was 94 g/t, and the collection rate was 100% (Table 5-4).

5.2.2 Mix used building: B5-5

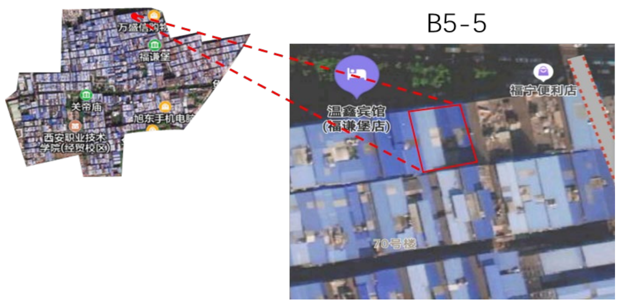

Figure 5-11 The location and satellite map of B5-5.

Figure 5-12 Aluminium-containing building parts of B5-5.

B5-5 was a reinforced-concrete building with a floor area of 1740 m^2. The landlord lived on the first and second floors, and the third to seventh floors were rented out to tenants. As shown in Figure 5-12, aluminium windows and doors were the only aluminium-containing building parts during demolition and collection. As shown in Table 5-4, 0.33 t of aluminium scrap was collected, and the aluminium share was 202 g/t, which was higher than that of B1-21. The collection rate was 100%.

5.2.3 Mix used building: B8-30

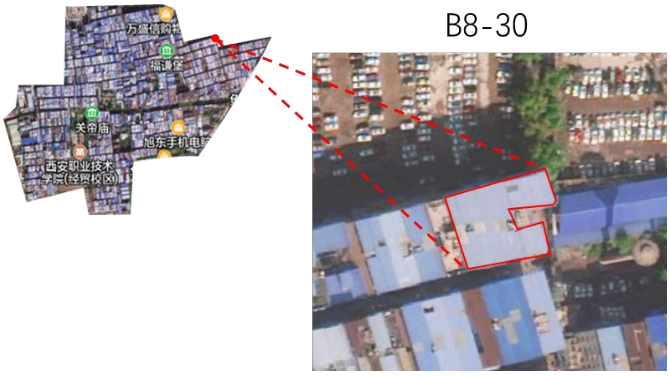

Figure 5-13 The location and satellite map of B8-30.

Figure 5-14 Aluminium-containing building parts of B8-30.

B8-30 was a reinforced-concrete structure with a floor area of 2376 m^2 with eight floors. Aluminium windows and doors were the only aluminium-containing building parts in this commercial building. The quantity of aluminium scrap was 0.49 t. The aluminium share of this building was 238 g/t, which was the highest, compared with B5-5 and B1-21. The aluminium collection rate was 100%.

Both Yuhuazhai and Wangtan were urban villages; however, Yuhuazhai had a much higher aluminium share compared with Wangtan, because the buildings in Yuhuazhai were mainly used for commercial purposes. Building owners can make a profit from upgrades and renovations.

Table 5-4 Demolition data on the Yuhuazhai investigation.

	B1-21	**B5-5**	**B8-30**
Floor area (m^2)	1405	1740	2376
Al (t)	0.19	0.33	0.49
Mass of building (t)	2111	1499	2047
Al share (g/t)	94	202	238
Collection rate (%)	100%	100%	100%

5.3 Shanghai

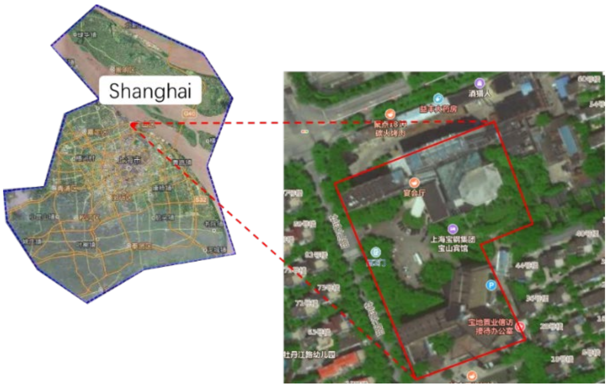

Figure 5-15 The location and satellite map of the Baoshan Hotel.

Shanghai is the biggest city in China's southeast region and was used in this study as the representative of eastern China. In this city, we investigated the Baosteel Group's Baoshan Hotel renovation project.

The Baoshan Hotel is a four-star hotel in Shanghai's Baoshan district. It was established in 1980 and was the 11th hotel in Shanghai authorised to accommodate international guests. The Baoshan Hotel is a reinforced-concrete structure covering a floor area of 52820 m^2, with 337 rooms, over a dozen venues with service capacity ranging between 30 and 500 people, and four themed restaurants. To meet customer needs and optimise the landscape, the Baosteel Group decided to refurbish this hotel in 2019. It was the only building we surveyed that was not demolished; therefore, we could not obtain accurate data on the total mass of the building. Instead, we used the experience data provided by the local demolition company. Like the other surveys, we identified the types of aluminium-containing building parts and collected data on the weight of the aluminium scrap.

Figure 5-16 Aluminium-containing building parts of the Baoshan Hotel.

As Figure 5-16 shows, aluminium curtain wall frames and aluminium windows were the aluminium-containing building parts in this commercial building. The aluminium scrap quantity was 17 t, the aluminium share was 374 g/t, and the collection rate was 100% (Table 5-5). The Baoshan Hotel is the most famous and well-designed building among all buildings surveyed in this study. However, it did not have the highest aluminium share, because it was built in 1980, when aluminium was not a popular building material in China.

Table 5-5 Demolition data on the Baoshan Hotel investigation.

Baoshan hotel	Quantity
Floor area (m^2)	52820
Al (t)	17
Mass of building (t)	45506
Al share (g/t)	374
Collection rate (%)	100%

5.4 Xiamen

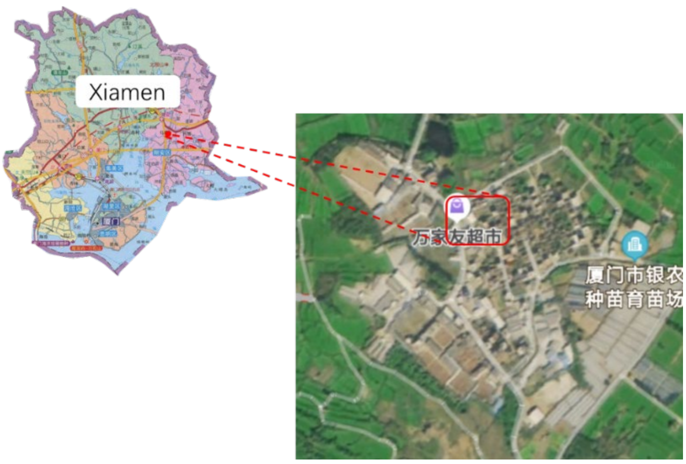

Figure 5-17 The location and satellite map of Diantouzhuang self-built house.

Xiamen is a city in Fujian province, located in southern China, and is very close to Taiwan. It was used in this study as the representative of southern China. Diantouzhuang is a village in the Xiang'an district and was slated for demolition in 2020. This village had 144 residential houses covering a floor area of 44,068 m^2. Buildings in this village were very similar in structure and appearance.

We selected a self-built house as a sample. This brick-concrete house was built in 1999 and had a floor area of 245 m^2 and three floors. The homeowner paid a large sum of money to build this house, as he had hoped to live there for a long time. All the windows, doors, and partition frames were made with aluminium. This building was not demolished during this survey. By measuring the size of the aluminium-containing building parts, we collected data on the aluminium scrap weight. For the mass of the building, we used the experience data from the local demolition company.

Figure 5-18 Aluminium-containing building parts of the Diantouzhuang self-built house.

In this house, only the window, door, and partition frames contained aluminium. There were 31 windows, one door, and one partition (Figure 5-18). The quantity of aluminium scrap was 0.16 t. The aluminium share of this house was 753 g/t, which was the highest among all the buildings we surveyed. Buildings in southern China are required to be typhoon-resistant; therefore, aluminium windows and doors are highly popular in coastal cities. Owing to the high average income, residents of coastal cities can afford aluminium-containing building parts that are priced higher than other materials. During our interview, the houseowner stated that he planned to remove and sell all the aluminium frames himself before he moved out.

Table 5-6 Demolition data on the Diantouzhuang investigation.

Diantouzhuang self-built house	**Quantity**
Floor area (m^2)	245
Al (t)	0.16
Mass of building (t)	211
Al share (g/t)	753
Collection rate (%)	100%

5.5 Characteristics and patterns of aluminium scrap production

Based on a literature review and on-site investigations and interviews, aluminium windows and doors frames are the main aluminium-containing parts in Chinese buildings. However, as the prices for aluminium frames tend to be high, not all Chinese buildings use them. Whether aluminium parts are used is influenced by factors such as design year, income, climate, and building purpose. Newer buildings are highly likely to use aluminium frame. High-income residents are also more likely to use aluminium frames. Strong winds along the coast lead to buildings in coastal cities tending to use aluminium frames as well. Compared with commercial residential buildings, self-bult homes may be more likely to have aluminium frames. Non-residential buildings usually have a high aluminium content.

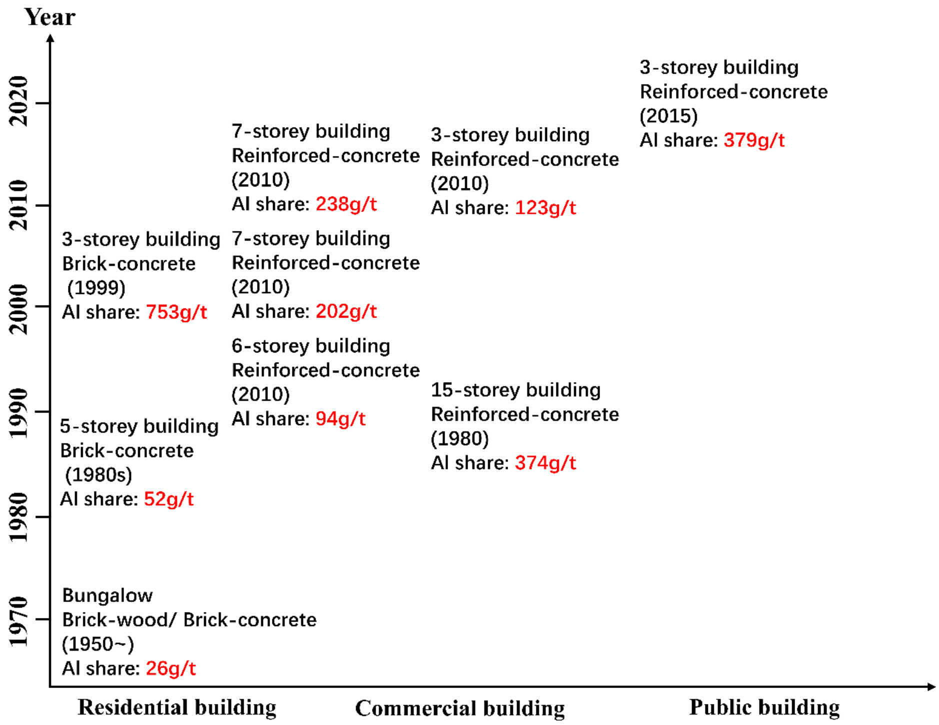

Figure 5-19 Main information and indicators of surveyed buildings.

The potential aluminium content in residential buildings spans a very large range, with residential buildings showing both the highest and lowest quantities of aluminium. In commercial buildings, the aluminium content is relatively concentrated (Figure 5-19). Compared with many residential and commercial European buildings (Table 5-7), China's residential buildings contain more aluminium, while China's commercial buildings contain less, respectively. Furthermore, the difference in aluminium shares between China's residential and commercial buildings is smaller than that of European buildings. This is because currently, EOL buildings in China were mostly either built by the property owners or by companies before 1990, and some are used for both residential and commercial purposes. China's residential buildings, especially those facing the street, have shops on the first floor, which are more likely to use aluminium windows and doors or aluminium-plastic boards. Building owners in China's urban villages rent out their extra rooms for accommodation or other business uses, which increases the aluminium share of the entire building.

Table 5-7 Comparison between Chinese and European buildings.

Building Type	**Location**	**Aluminium share (g/t)**	**Collection rate (%)**
Residential building	Beijing: bungalow	26	100
	Beijing: five-story building	52	100
	Xiamen: three-story building	753	100
	France	18	31
	The Netherlands	32	95
	The Netherlands	49	95
Commercial building	Beijing: Tongzhou	118	96
	Beijing: Shunyi	379	16
	Xi'an: B1-21	94	100
	Xi'an: B5-5	202	100
	Xi'an: B8-30	238	100
	Shanghai: Baoshan Hotel	374	100
	France	640	92
	Germany	7500	98
	Germany	1750	98
	Italy	430	94
	Spain	4000	95
	The United Kingdom	6100	96

All the aluminium window and door frames in these surveys were collected during the removal of the accessory structure. However, aluminium-plastic boards were not collected during the demolition process. This is because aluminium-plastic boards have a low aluminium content; however, aluminium extrusion results in the highest proportion (approximately 86%) of total aluminium consumption in buildings. Thus, there is reason to believe that the recycling rate of waste aluminium in China should be above 90%.

6. Aluminium scrap collection: surveys of aluminium scrap dealers and C&DW recycling plants

We mainly conducted on-stie surveys and interviews of aluminium scrap dealers and C&DW recycling plant employees in Beijing and Xi'an. In addition, we investigated Henan province, which has one of the biggest agglomerations of the aluminium collection and recycling industry. Based on the collected information, we summarise the aluminium scrap collection network and key points below.

6.1 Aluminium scrap collection at the demolition site

Aluminium collection networks are very simple and have only one or two nodes. This is because short collection routes can reduce collection costs and increase profits for scrap metal dealers and collectors (Figure 6-1).

Figure 6-1 Collection process for aluminium scrap from EOL buildings.

Demolition companies do not usually remove aluminium-containing building parts by themselves. Instead, demolition companies hire aluminium scrap dealers and collection centres hired to remove these building parts at the demolition sites for free and buy aluminium frames by weight.

Considering transportation and time costs, aluminium scrap dealers only choose EOL buildings with large quantities of aluminium scrap. When deciding whether to go to a demolition site, they will first ask for the quantity of aluminium scrap. If it is large enough and the price is reasonable, they will collect aluminium scrap by themselves and it directly to a recycling factory. However, most of the time, aluminium scrap will be temporarily stored in dealers' yards and sent to factories after several hours or days.

For demolition projects that generate less aluminium scrap, demolition companies will hire workers from a collection centre to remove not only the aluminium scrap but also plastic scrap, copper scrap, and other valuable items. Because the amount of aluminium scrap they collect in one demolition project is not large enough to send directly to aluminium dealers, aluminium scrap will be stored for several days and sent to aluminium dealers along with aluminium scrap from other sources.

6.2 Aluminium scrap collection in C&DW recycling plant

The four cities included in this study had C&DW recycling plants. The demolition waste generated from demolition projects in Beijing and Xi'an are sent to designated C&DW recycling plant, and we traced these flows.

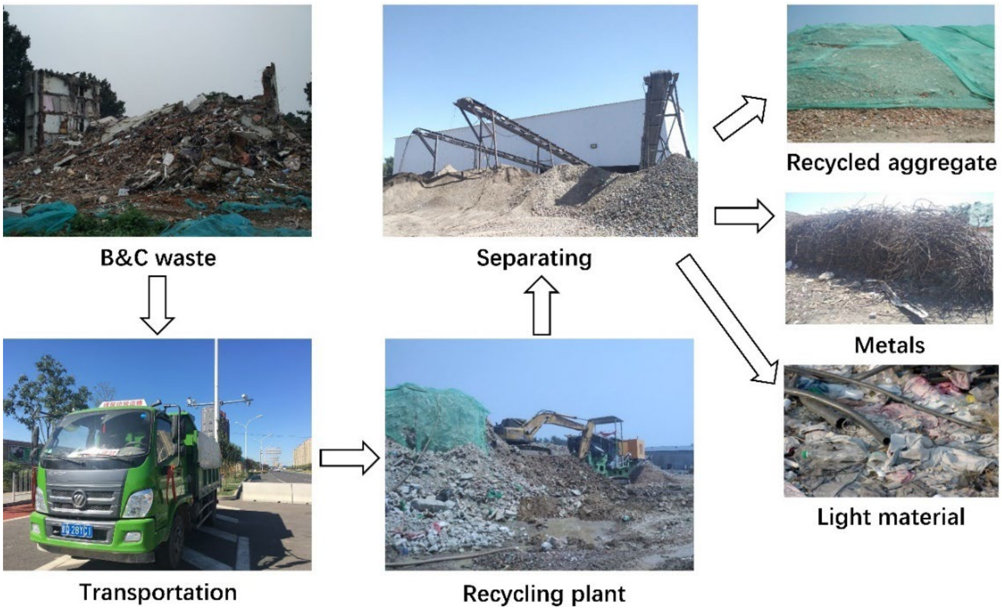

Figure 6-2 C&DW recycling process at recycling plants.

Aluminium scrap that was not collected at demolition sites will be torn down during the major structure demolition process and mixed with C&DW. In the present study, this comprised aluminium-plastic boards from Beijing projects. Demolition companies packed this C&DW, which contained aluminium scrap, in specific vehicles and sent it to designated recycling plants. At recycling plants, C&DW will be crushed and sorted into three parts (Figure 6-2), and aluminium scrap may be picked out during this process and sold to recycling factories. However, in the Beijing surveys, aluminium-plastic boards were not collected, but instead were sent to a waste incineration plant with other light materials. According to our interviews with employees at C&DW recycling plants, aluminium scrap used to be collected by these plants; however, it was mainly from durable consumer goods that contain aluminium, such as aluminium pots and furniture. This was because these goods are not easily crushed during this process and can be picked out.

6.3 Sorting and pre-treating of aluminium scrap

All aluminium scrap in the market will be sorted into different categories by scrap dealers based on the type of aluminium alloy (Figure 6-3). There are two main groups: wrought scrap and casting scrap. Wrought scrap includes old kitchenware (1XXX/3XXX), waste aluminium cans (3XXX/5XXX), scrap wire (1XXX), old printing plates (1XXX), old sheets, old roller doors, old frames (6XXX), and other old extrusions. Casting scrap includes old bicycle, motorcycle, and car wheels; pistons; radiator tanks; and engines, as well as other aluminium scrap from machines. Aside from this aluminium scrap, we also found casting scrap and wrought scrap fragments in aluminium recycling factories. It is not possible to determine the original purpose of these fragments; however, we do know they are from dismantling objects such as cars, ships, and mechanical equipment.

Aluminium plates for ceilings and walls, including aluminium-plastic boards and aluminium frames, are the main types of aluminium scrap collected from EOL buildings. According to our on-site interviews, waste aluminium-plastic boards were not collected for a long time but were instead sent to landfills or incineration plants. However, more recently, some aluminium dealers have begun to collect aluminium-plastic boards. Aluminium plastic boards are divided into aluminium plates and plastic plates, which are recycled at different plants. However, we do not know what proportion of aluminium-plastic boards are collected. As aluminium-plastic boards were not collected in our surveys, the collection rate may still be low.

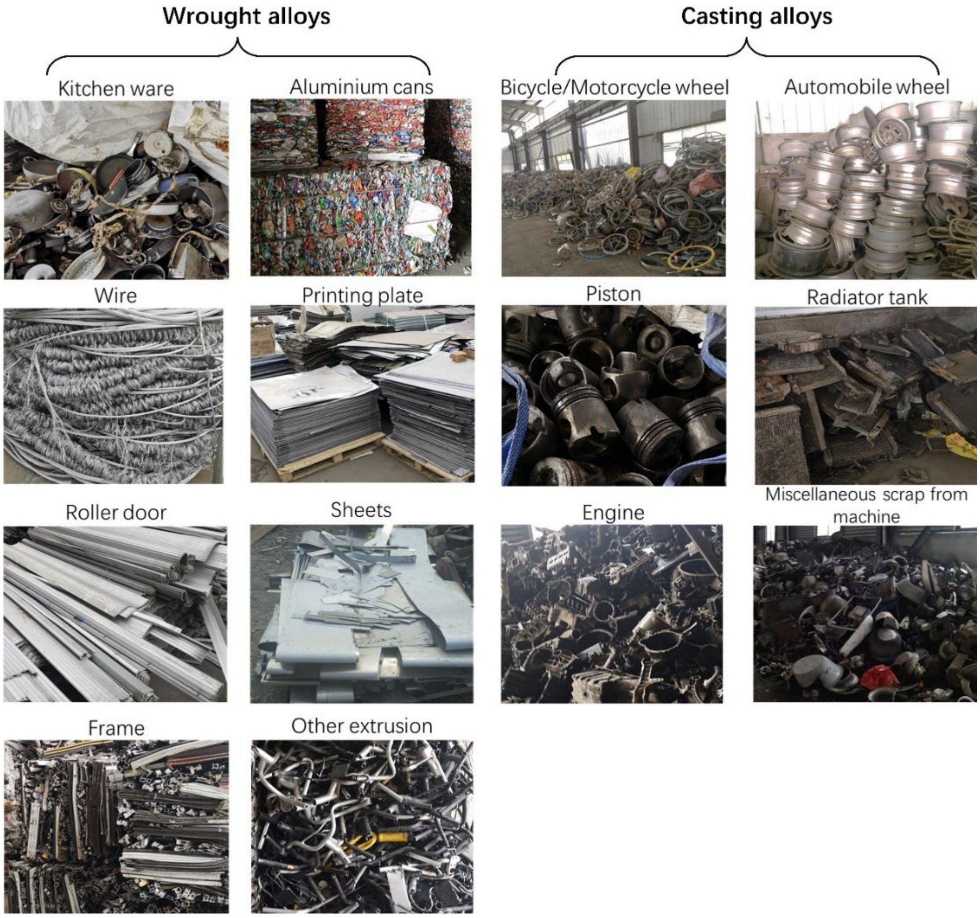

Figure 6-3 Categories of aluminium scrap in aluminium scrap market.

Aluminium scrap may be mixed with other metals, especially steel. For example, steel nails are generally used to install aluminium windows. Aluminium conductor steel reinforced (ACSR) contains steel. Therefore, before it is refined, aluminium scrap will be separated, and other metals will be picked out by some machines developed by recycling companies (Figure 6-4). This can happen at both collection and recycling companies. There are some typical pre-treatment processes. Pictures 1–4 show the removal of a steel wire from an aluminium conductor. Some companies use specialised equipment, while others have workers to perform the task. To remove the iron and steel from aluminium scrap, some companies will use large crushing equipment (Picture 5) to break up large scrap pieces and pick out the iron scrap (Picture 6). However, some companies still rely on people to sort aluminium scrap (Picture 8). To facilitate transportation and weight calculation, 'clean' aluminium scrap will be compressed into a cube (Pictures 9 and 10).

Figure 6-4 Aluminium scrap pre-treatment process.

7. Aluminium recycling: recycling industry surveys

We surveyed five aluminium recycling enterprises: one large enterprise (A) that has more than 500 thousand tons of annual output, two medium-size enterprises (B and C) that produce 100–200 thousand tons annually, and two small-scale companies (D and E).

7.1 Basic information of these five enterprises

Enterprise A is located in central China, and has nine factories, including five aluminium plate factories, one casting ingot factory, one flat ingot factory, one aluminium rod factory, and one extrusion billet factory. Only the extrusion billet factory uses old window frame scrap to produce secondary aluminium, which has an annual output of 100,000 tons. Except for the casting ingot factory and extrusion billet factory, the other factories only use new rolled scrap, scrap aluminium wire, and old printing plates, which are 1 series aluminium scrap that have high levels of purity, to produce secondary flat ingot, aluminium sheets, plates, and rods. This enterprise produces secondary aluminium alloys by basically using the same type of aluminium scrap. This is because this enterprise is supported by more than 40,000 residents who collect scrap metal all over China and can purchase aluminium scrap based on alloy types.

Enterprise B is in southern China and produces both casting ingots (approximately 100,000 tons) and extrusion billets (approximately 70,000 tons) by using all types of aluminium scrap. Owing to the lack of stable sources for aluminium scrap, this enterprise cannot purchase aluminium scrap based on alloy types, resulting in more impurities in the secondary aluminium it produces. To uncover the complex situation, we collected more detailed data about this enterprise's refining and remelting processes.

Enterprise C is in northern China. It is a subsidiary of a well-known enterprise that produces a high quantity of aluminium wheels by primary ingots. This enterprise only produces casting ingots used for transportation equipment parts, such as engines, by using both casting scrap and wrought scrap (5XXX/6XXX), including old window frames. That is because secondary casting alloys produced by this enterprise are mainly Al-Si-Mg casting alloys, which are like 5 series and 6 series wrought alloys.

Enterprises D and E are also located in northern China. Enterprise D is a refiner and does not use wrought scrap to produce casting ingots. Enterprise E is a remelter and only uses aluminium frame scrap to produce extrusion billets.

7.2 Basic aluminium recycling process in China

Based on the on-site surveys and interviews, in China, much like in the European aluminium recycling industry, secondary casting alloys are mainly produced by casting alloy scrap, while secondary wrought alloys are mainly produced by wrought alloy scrap. However, the mixed use of casting and wrought alloy scrap to produce secondary aluminium still exists. Different recycling companies have very similar production processes for each type of secondary aluminium alloy, while production processes of casting alloys and wrought alloys have few differences (Figure 7-1).

After being pre-treated as described in Section 6.3, suitable clean scrap will be sent into a melting furnace according to production orders, where it will be melted into liquid. Salt will be added to the furnace to further remove impurities known as aluminium skim and dross in molten aluminium. Aluminium skim and dross, which still have high aluminium content, will be bailed out and sent to another small furnace. In the small furnace, aluminium can be extracted from the skim and dross. After removing impurities several times, molten aluminium in the melt furnace will be clean. Then, technicians will test the components of the molten aluminium and put suitable type and quality alloys into molten aluminium to produce products ordered by customers. Casting alloys and wrought alloys have very different components; therefore, the alloys added to molten aluminium in these two production processes will be very different.

In the casting ingots production process, after adjusting the components, molten aluminium will flow into an ingot casting machine and be solidified. For wrought alloys, molten aluminium will be poured into a purification system to further remove gasses and impurities, as wrought alloys are always required to be of higher quality than casting alloys. Next, the molten aluminium will flow into an extruder or rolling machine. Extrusion billets and other rolling products will then be produced.

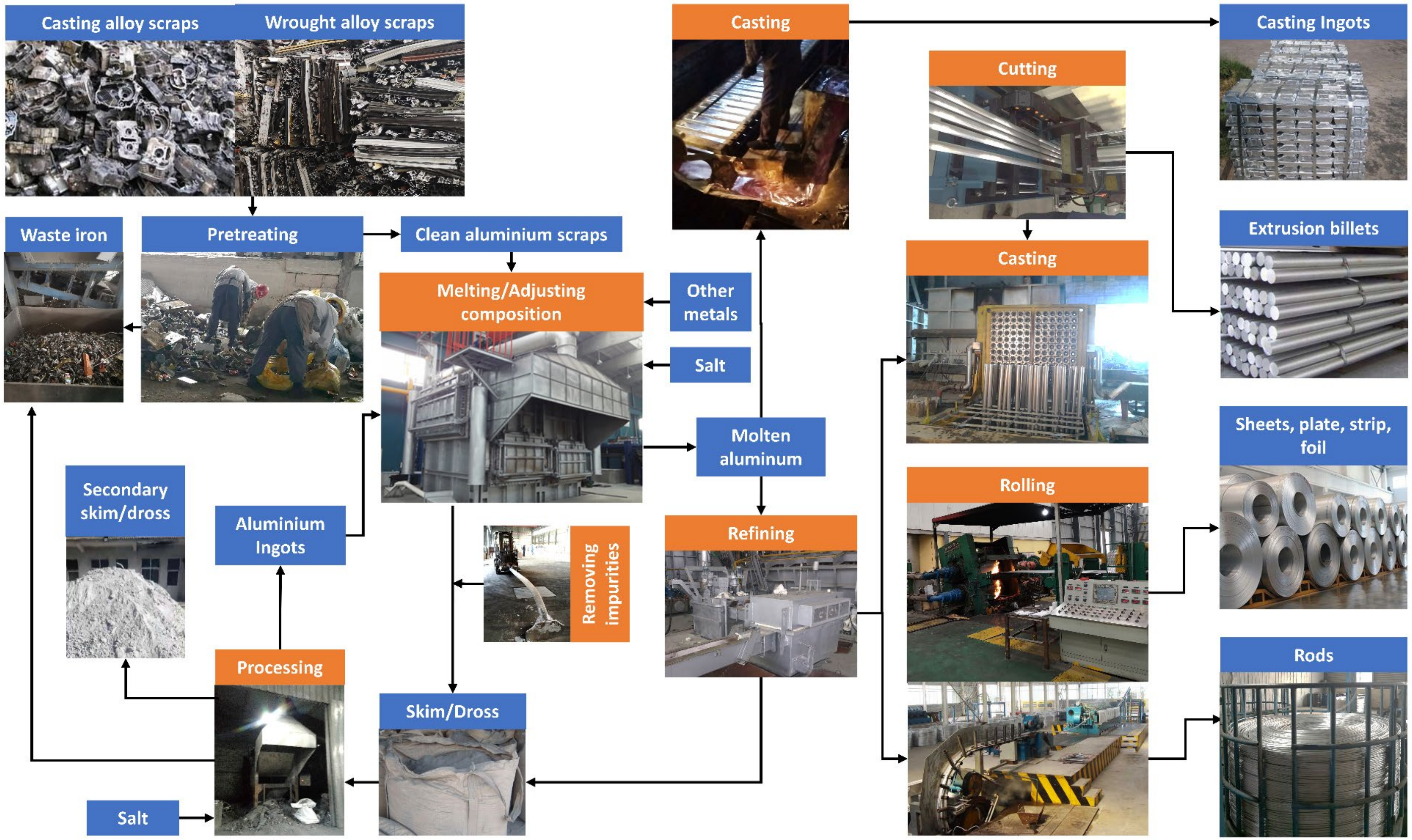

Figure 7-1 Basic aluminium recycling process in China.

Large recycling companies usually have more advanced equipment and higher techniques. For example, major companies use magnetic separators to remove iron, while small companies separate waste iron using human labour. Small companies use reverberatory furnaces to produce ingots, while major companies use double-chamber furnaces. In addition, there is a high possibility small companies will produce non-standard ingots.

7.3 Recycling information and indicators

According to the surveys, aluminium frame scrap is the main type of aluminium building scrap according collected during in demolition projects, and other aluminium building scrap was not found at recycling plants. Therefore, we mainly focused on the recycling processes for aluminium frame scrap from buildings. All the surveyed factories were divided into two production processes: remelting and refining.

7.3.1 Remelting

The material flow diagram of the remelting process for each enterprise is shown in Figure 7-2. Aluminium frame scrap is mainly used to produce extrusion billets, which is the semis to produce aluminium window and door frames. This is because recycling aluminium frames to produce the same products does not require extra metal, which has the lowest recycling cost. For the same reason, recycling enterprises seldom use casting scrap to produce wrought alloys. Casting scrap has higher proportions of silicon and steel compared with wrought scrap. If casting scrap is used, primary aluminium needs to be added to adjust the silicon and steel concentration, which is not cost-effective. According to the survey data, producing 1 t of secondary extrusion billets will use 0.75~0.95 t of aluminium frame scrap in China.

Aluminium frame scrap generation is much smaller that aluminium frame demand, because the use of aluminium door and window frames continues to increase. Hence, not all recycling enterprises have enough aluminium frame scrap to produce extrusion billets. Enterprise A is supported by a local collection group, and Enterprise E is located close to a metropolis. This city was the first to use aluminium doors and windows in China, and can generate large amounts of aluminium frame scrap every year, thereby providing enough scrap to Enterprise E. However, Enterprise B, may be due to the low level of production technology or insufficient aluminium frame scrap in some period, more other wrought scrap and some casting scrap have been used to produce extrusion billets. Primary aluminium and magnesium are also added to adjust the aluminium scrap's composition.

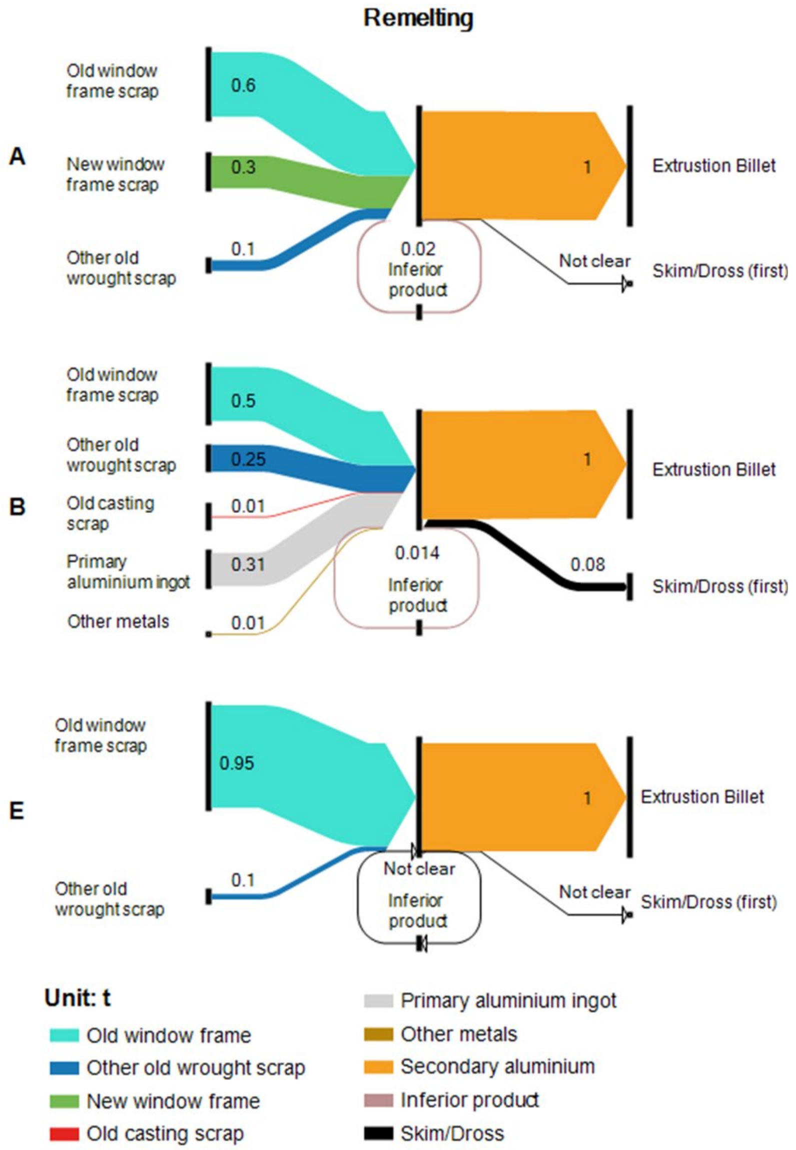

Figure 7-2 Material balance of the remelting process in Enterprises A, B, and E.

The other wrought scrap used by Enterprises A and E are scrap wire and scrap printing plates. Other than wires and printing plates, Enterprise B also uses 5052. The composition of wire and printing plates is very similar to that of pure aluminium, and enterprises generally use them to replace electrolytic aluminium. Both aluminium frames and 5052 are Al-Mg alloys; thus, 5052 is also a good raw material to use for extrusion billets.

7.3.2 Refining

The material flow diagram of the refining processes used by the enterprises are shown in Figure 7-23. As Enterprises A and D do not use aluminium frame scrap to produce casting ingots, we only show the material flow diagrams for Enterprises B and C.

According to the collected data, producing 1 t casting ingot may use 0~0.39 t wrought scrap, including 0~0.15 t aluminium frame scrap. Other wrought scrap is mainly from scrap wires and waste cans. The proportion of wrought scrap in the production materials of secondary casting alloys is not very high. The first reason for this is that using wrought scrap to produce casting ingot is not cost-effective. Wrought scrap is priced higher than casting scrap. Furthermore, owing to the higher silicon concentration of casting ingots, if more wrought alloy scrap is used, refiners should add more silicon, which is priced very similarly to aluminium. The second reason is that it is very difficult to produce high-quality ingots by using wrought scrap, because wrought scrap contains some metals, such as Cr, that are harmful to some types of casting ingots and decrease product quality. This may decrease the profits that enterprises can obtain from producing secondary casting alloys.

Enterprise C uses approximately 0.0675 t aluminium frame scrap for 1 t casting ingots. This is because C mainly produces Al-Si-Mg casting alloys, and aluminium frames are Al-Mg wrought alloys. The main metals in these two products are very similar. Other wrought scrap is mainly from scrap wires. Enterprise B uses approximately 0.15 t of aluminium frame scrap for 1 t casting ingots. Other wrought scrap Enterprise B uses are mainly scrap wires and aluminium cans. However, Enterprise B mainly produce two types of casting ingots: YL112 (A380) and YL113 (A383, A384). Both are Al-Si-Cu alloys, which have very different components compared with aluminium frame scrap and waste cans. Thus, primary aluminium ingots should be used to produce casting alloys.

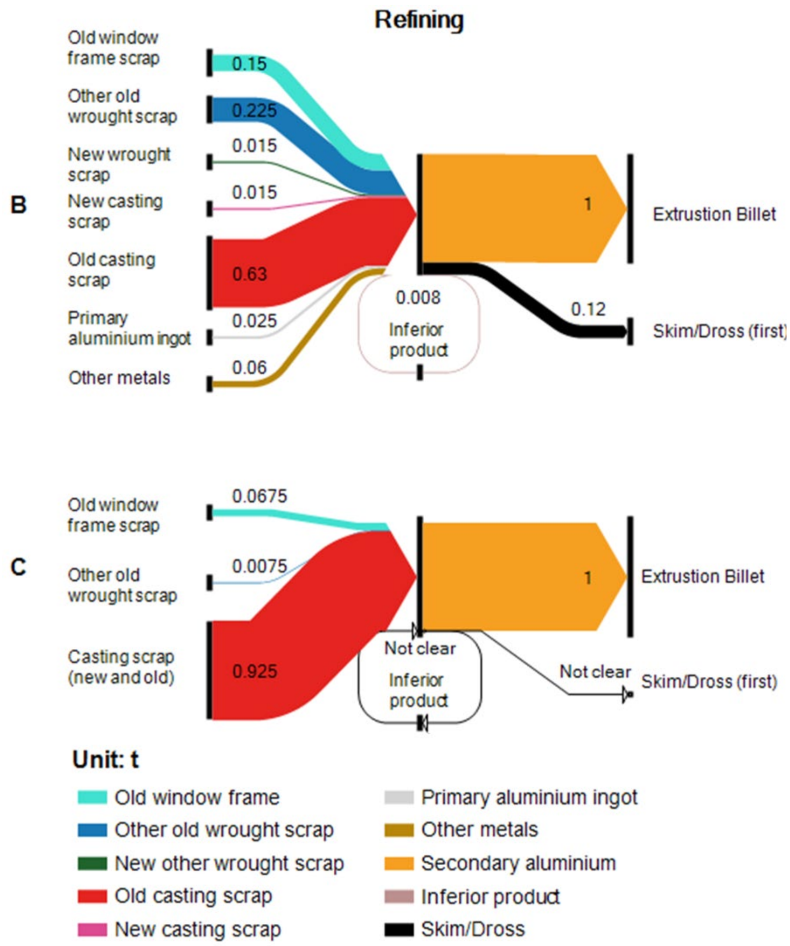

Figure 7-3 Material balance of the refining process in Enterprises B and C.

7.4 Conclusions regarding the recycling industry

Except for Enterprise B, all the enterprises used recycled aluminium scrap to produce the same types of aluminium alloys. Especially in the production of secondary extrusion billets, casting scrap is not used in the production materials. It is also the most economical and environmental recycling strategy. Therefore, it is reasonable to posit that secondary aluminium production in Chinese enterprises has reached a higher level than previous studies have indicated. However, the production of secondary casting ingots in China still uses wrought scrap as production materials, which is an obstacle to the efficient utilisation of wrought scrap and reduces the profitability of aluminium recycling enterprises. Therefore, the need to address this issue is urgent.

8. Discussion and implications

8.1 Challenges of aluminium scrap recycling from EOL buildings in China

Based on the information that we collected during our surveys, some challenges of aluminium scrap generation, collection, and recycling in China have been preliminary identified, which are as follows:

(1) To improve the aluminium scrap collection rate, China needs to pay attention to collecting aluminium scrap from all types of buildings, instead of focusing on commercial buildings alone. This is because aluminium shares are very similar among different types of Chinese buildings.

(2) Most demolition enterprises do not have the ability to dismantle aluminium-containing building parts, and mainly rely on collectors to remove aluminium-containing building parts. However, collectors usually only have the ability to dismantle simple building components, such as doors, windows, and wires, while they are not able to sufficiently dismantle other components, such as decorative aluminium panels for exterior walls. This may be why no aluminium-plastic boards were collected in the surveyed projects.

(3) Demolition enterprises seldom remove parts from building interiors, such as decorative panels for interior walls, ceilings, tubes, hardware, and furniture. Most of these building parts are currently made using plastic, steel, and wood; however, there are also some aluminium plates used in these parts, and families are increasingly using aluminium furniture. Therefore, it may limit the future collection rate of aluminium scrap from buildings in China. Although valuable aluminium scrap in these building parts can be sorted and collected at C&DW recycling plants, this scrap may be mixed with impurities, affecting the quality of secondary aluminium.

(4) The pre-treating capability for new types of aluminium-containing materials is insufficient. The development of pre-treating capability for aluminium scrap has been unable to maintain the same pace as the development of aluminium containing materials. For example, aluminium-plastic boards were introduced in China in the late 1980s; however, for a long time, all aluminium-plastic boards were sent to landfills or incinerated. Enterprises only recently gained the capability to split these into aluminium boards and plastic boards and recycle them separately.

(5) In China, some secondary casting alloys are still produced using wrought scrap. Enterprises generally use aluminium scarp cans to produce secondary casting alloys. This will increase the impurity concertation in secondary aluminium each time it is recycled and decrease the total number of times that aluminium can be recycled. Therefore, recycling enterprises in China cannot gain profit as much as they should.

8.2 Limitations

Using on-site investigations and interviews with practitioners, we collected first-hand information and data on China's demolition industry, aluminium scrap collection process, and recycling industry. The entire process from production to recycling of aluminium scrap from EOL buildings was traced and studied. However, the surveyed demolition projects, scrap metal collectors and dealers, and recycling enterprises were insufficient in number, compared with the total number of related enterprises in China. Therefore, the results of this study only show a profile of the current situation of these industries. However, since there are few investigations on China's recycling aluminium industry, this study provides some implications for relevant researchers and practitioners.

China has the largest building and construction stock worldwide, resulting in a large aluminium stock in Chinese buildings. Recycling aluminium scrap from buildings in China has had an effective and significant impact on the global environment. Therefore, it is necessary to conduct more research on aluminium scrap generation and recycling in China and improve the collection rate of aluminium scrap and quality of secondary aluminium products.

9. Reference

1. International Aluminium Institute. Global aluminium cycle 2019. Available at https://alucycle.world-aluminium.org/public-access/ (2021).

2. Beijing Review. China needs to overcome greater challenges than developed countries to meet its carbon-neutral target- China.org.cn (2021).

3. Dai, M., Wang, P., Chen, W.-Q. & Liu, G. Scenario analysis of China's aluminum cycle reveals the coming scrap age and the end of primary aluminum boom. *Journal of Cleaner Production* **226,** 793–804; 10.1016/j.jclepro.2019.04.029 (2019).

4. Liu, G., Bangs, C. E. & Müller, D. B. Stock dynamics and emission pathways of the global aluminium cycle. *Nature Clim Change* **3,** 338–342; 10.1038/nclimate1698 (2013).

5. Efthymiou, E., Cöcen, Ö. N. & Ermolli, S. R. Sustainable Aluminium Systems. *Sustainability* **2,** 3100–3109; 10.3390/su2093100 (2010).

6. EAA. Collection of aluminium from buildings in europe. European Aluminium Association, 2004.

7. Billy, R. Material Flow Analysis of Extruded Aluminium in French Buildings. Opportunities and Challenges for the implementation of a Window-to-Window System in France. Master. Norwegian University of Science and Technology, 2012.

8. Tanikawa, H. & Hashimoto, S. Urban stock over time: spatial material stock analysis using 4d-GIS. *Building Research & Information* **37,** 483–502; 10.1080/09613210903169394 (2009).

9. Marshall Jinlong Wang. Aluminium in Green Building. The Aluminum Association, 2015.

10. Lu, W. *et al.* An empirical investigation of construction and demolition waste generation rates in Shenzhen city, South China. *Waste management (New York, N.Y.)* **31,** 680–687; 10.1016/j.wasman.2010.12.004 (2011).

11. Niero, M. & Olsen, S. I. Circular economy: To be or not to be in a closed product loop? A Life

Cycle Assessment of aluminium cans with inclusion of alloying elements. *Resources, Conservation and Recycling* **114,** 18–31; 10.1016/j.resconrec.2016.06.023 (2016).

12. IAI. Global Aluminium Recycling. A Cornerstone of Sustainable Development. International Aluminium Institute, 2006.

International Aluminium Institute

2 Duke Street, St James's. London. SW1Y 6BN

United Kingdom

info@interntional-aluminium.org

international-aluminium.org

Urban Metabolism Lab (UM Lab)

Professor Wei-Qiang Chen

1799 Jimei Road, Xiamen, China, 361021

wqchen@iue.ac.cn

uree.org