Using decomposition analysis to forecast metal usage in the building stock

Hiroki Hatayama and Kiyotaka Tahara

Research Institute of Science for Safety and Sustainability, National Institute of Advanced Industrial Science and Technology, 16-1 Onogawa, Tsukuba, Ibaraki 305-8569, Japan
E-mails: h-hatayama@aist.go.jp and k.tahara@aist.go.jp

As large amounts of materials are used and have accumulated in buildings and civil engineering projects, it is necessary to understand material flow in terms of construction sectors for resource management. The consumption, discard and in-use stock of four metals (steel, aluminium, copper and zinc) in Japan’s building stock are forecast through to 2050. To clarify the factors that affect metal stocks and flows in construction, the metal consumption was decomposed into annual new floor area constructed and metal intensity (i.e. the amount of metal used per unit floor area). The decomposition was meaningful for understanding characteristic patterns of factors of different metals and for envisaging future scenarios based on past trends. It was estimated that the annual new floor area constructed will remain at current levels, whereas metal intensity will have a significant impact on stocks and flows. The methodology developed in this study can be used to evaluate the impact of technology changes that would take place in building and civil engineering projects.

Keywords: building stock, decomposition analysis, forecasting, material flow analysis, resource flows, trend analysis, Japan

Introduction
The creation and enhancement of residential environments and social infrastructure are very important for the formation and activity of human societies. Today in Japan, the construction industry, which includes the building and civil engineering industries, is still a large consumer of metal resources compared with other end users. In recent years, the construction industry accounted respectively for 35% and 15% of domestic steel and aluminium consumption. Moreover, previous studies indicate that existing building and civil engineering projects account for 65% and 50% of the steel and aluminium in-use stocks (Hatayama, Daigo, Matsuno, & Adachi, 2009, 2010). The construction industry occupies an important position in considering the resource management of metals. Therefore, estimates of metal stocks and flows in terms of building and civil engineering are useful information for the metal manufacturing industry. At the same time, such estimates enable the identification of potential recycling toward a reduction in primary metal production and resulting energy savings.

Japan has a mature residential environment and social infrastructure and a vigorous industry that is shifting to products and services that offer increased convenience. Annual new floor area constructed (hereafter, ‘new floor area’) in Japanese buildings corresponds to this transition of industrial structures, increasing from 50 million m²/year in 1960 to 250 million m² in the latter half of the 1990s, before declining to around 150 million m²/year currently (Construction Research Institute, 2012). However, the construction industry did not necessarily track these changes in metal consumption. While aluminium consumption exhibits a similar inverse U-shaped curve as the new floor area, steel and copper consumption show no significant decline after 1990 except during the economic crisis of the late 2000s. This would have been led by a change in metal consumption per unit of new floor area due to the changes in housing structures and products used to create residential environments, and also due to improvements in production technologies for building materials. These variations between metals must be reflected in the forecast of metal usage in buildings.

Forecasts of the stocks and flows in anthropogenic metal cycles have been presented with dynamic material flow analysis (MFA). Some studies, after
employing the assumption that per capita metal stock will increase along a logistic curve and saturate in future, estimate the amounts of worldwide stocks and flows for several end-uses (Liu, Bangs, & Müller, 2013; Pauliuk, Milford, Muller, & Allwood, 2013). In a detailed analysis on the building sector, Bergsdal, Brattebø, Bohne, and Müller (2007) estimate future stocks of concrete and wood in Norway by simulating floor area, material intensity, change in average lifetime, etc. Hu, Pauliuk et al. (2010) also estimate future steel stock in buildings in China using a similar approach. Such decomposition must be effective in evaluating how change in an individual factor would affect the future material stocks and flows, especially as each of the decomposed factors is well modelled from a dynamic perspective (Kohler & Hassler, 2002). It will also be possible to show future consumption scenarios in a way that considers the effects of social and technology changes on these factors.

The goal of this study is to present the metal cycle of steel, aluminium, copper and zinc in terms of the Japanese construction sector through to 2050. The amount of annual consumption of each metal was calculated by decomposing it into new floor area and metal intensity. In this procedure, characteristic trends for these factors for each metal were clarified. The trends were then used to envisage several scenarios of future demand and estimate how the individual factors would affect the dynamic changes in the amounts of stocks and flows of construction metals.

**Methods**

The consumption of metal $m$ for the construction sector in year $t$ ($C_{m,t}$) can be decomposed as in equation (1).

$$ C_{m,t} = F_t \times c_{m,t} $$

where $C_{m,t}$ is determined by two factors: the new floor area ($F_t$) and the metal intensity for $m$ ($c_{m,t}$). Based on the decomposition, several patterns of metal consumption can be presented through to 2050 with a combination of scenarios for $F_t$ and $c_{m,t}$ (Figure 1). To develop a future scenario for $F_t$, past changes in the per capita floor area ($a_t$) through to 2010 were first investigated. The past trends for $a_t$ were used to estimate future changes in the total

![Figure 1](image)
floor area \( (A_t) \), and future \( F_t \) values were then calculated from a dynamic model that describes the relationship between \( A_t \) and \( F_t \). In addition, \( c_{m,t} \) values from 1960 to 2010 were calculated to develop a future scenario for \( c_{m,t} \) with regression analysis. The scenarios for \( F_t \) and \( c_{m,t} \) generated six patterns of future metal consumption. Finally, in-use stock and discard amounts of metals were estimated by 2050 using a dynamic MFA model. The multiple scenarios for future \( F_t \) and \( c_{m,t} \) enabled the impact of each component on metal usage in the construction sector to be evaluated.

Forecast of new floor area

The estimates of future new floor area in this study were calculated from changes in floor area. The existing floor area provides residential and other spaces, therefore construction demand is generated when the amount of floor area does not reach a required level, i.e. when demand exceeds supply. This approach, which considers the state of the stock as the driving force for demand, has been used in previous MFA studies. With this concept, forecasts were also made for the floor area of residential structures. Müller (2006) and Hu, Bergsdal et al. (2010) show that the per capita floor area was 45 m\(^2\)/cap in the Netherlands and 20 m\(^2\)/cap in China in 2005, and then they develop future scenarios. The present study estimated the future domestic floor area \( A_t \) on the assumption that the per capita floor area \( a_t \) approximates the saturation value \( a_{sat} \).

To obtain the value for \( a_t \) in Japan through to 2050, the historical \( a_t \) value was calculated from statistics for 1960–2010 (Ministry of Internal Affairs and Communications, 1983–2010). The \( a_t \) in 2010 was 65.2 m\(^2\)/cap (including both housing and non-housing), from which the following three scenarios could be formulated for \( a_t \) from 2011 onwards:

- **low saturation level**: \( a_t \) remains at the 2010 level of 65.2 m\(^2\)/cap \( (a_{sat} = 65.2 \text{ m}^2/\text{cap}) \)
- **medium saturation level**: \( a_t \) increases to \( a_{sat} = 80 \text{ m}^2/\text{cap} \)
- **high saturation level**: \( a_t \) increases to \( a_{sat} = 100 \text{ m}^2/\text{cap} \)

The historical \( a_t \) values and the projections in these scenarios are shown in Figure 2 (also see Appendix A in the Supplemental data online).

The floor area \( A_t \) through to 2050 was calculated as per equation (2) by multiplying \( a_t \) by population figures \( (POP_t) \). Annual changes in \( A_t \) values can be represented as equation (3), where the new floor area is

\[
F_t \text{ and the demolished area is } D_t:
\]

\[
A_t = POP_t \times a_t \tag{2}
\]

\[
A_t - A_{t-1} = F_t - D_t \tag{3}
\]

The value of \( D_t \) was estimated from \( F_t \) of the past years and the lifetime of the buildings:

\[
D_t = \sum \tau F_{t-\tau} g(\tau) \tag{4}
\]

where \( g(\tau) \) is a proportion of buildings demolished \( \tau \) years after the start of construction. Using equations (3) and (4), \( F_t \) in a given future year was calculated using:

\[
F_t = (A_t - A_{t-1}) + \sum \tau F_{t-\tau} g(\tau) \tag{5}
\]

\( A_t \) was obtained from equation (2) for every year until 2050. Then \( F_t \) was sequentially calculated beginning from 2011 using the data on \( F_t \) for 1960–2010. A Weibull distribution was used to represent the distribution function of lifetime of the buildings:

\[
g(\tau) = \frac{m}{n^m} \tau^{m-1} e^{-(\tau/n)^m} \tag{6}
\]

Here, scale parameter \( n \) can be expressed using a shape parameter \( m \) and average life time \( \bar{\tau} \):

\[
n = \bar{\tau}/\Gamma\left(1 + \frac{1}{m}\right) \tag{7}
\]

The value of \( m \) was set to 3.5, which is a validated value for durable goods in Tasaki, Oguchi, Kameya, and Urano (2001). Average lifetime was determined based on Komatsu, Kato, Yoshida, and Yashiro (1992). This survey indicated that the average
lifetimes of Japanese typical constructions are 38.2 years for timber structures, 40.6 years for reinforced concrete buildings and 32.8 years for steel constructions. Therefore \( \tau \) was set to 40 years in this study.

In addition to construction and demolition, Sartori, Bergsdal, Müller, and Brattebo (2008) consider renovations in calculating dwelling stock. In their typical scenario, the average lifetime of dwellings in Norway is set at 100 years, with 40 years used as the period until renovation. By contrast, in Japan the average lifetime of buildings is approximately 40 years, and therefore the impact of renovation is deemed to be relatively small. Actually, the area of renovation in Japan was 1.26 million m\(^2\)/year in 2010, which was only 1% of the new floor area (Construction Research Institute, 2012). Therefore, metal consumption for renovation was not considered in this study.

**Forecast of metal intensity**

Historical changes in \( C_{m,t} \) for 1960–2010 were obtained by referring to several statistics and MFA studies as detailed below.

Data on annual steel consumption for the construction sector (building and civil engineering) were estimated from statistics (Japan Iron and Steel Federation, 2013). Besides the amount of steel directly consumed by the construction sector, parts of intermediate metal products were also regarded as the consumption for the construction sector based on the expert interview in Tamaki, Hayashi, Suzuki, and Tomota (2008). Aluminium is mainly used in buildings in the form of window frames, doors and interior/exterior products. The data on aluminium consumption since 1963 were obtained from Aluminium Statistics in Japan (Japan Aluminium Association, –2013). Copper consumption data for wire and cable was obtained from the Japanese Electric Wire & Cable Maker’s Association (http://www.copper-brass.gr.jp/), and data for the other products were obtained from the Japan Copper and Brass Association (http://www.jcma2.jp/index.html). Note that the amount of copper used for electric power transmission lines from power plants is not included in this study. Zinc is consumed in construction as galvanized steel. Therefore, the amount was estimated from the consumption of galvanized steel as presented in the past zinc study by Tabayashi, Daigo, Matsuno, and Adachi (2009). The estimated \( C_{m,t} \) value for each metal is shown in Appendix B in the Supplemental data online.

The \( C_{m,t} \) values from 1960 to 2010 were calculated for four metals by dividing these \( C_{m,t} \) values by the \( F_t \) value for each year. Then two scenarios were set for future \( C_{m,t} \):

- the \( c_{m,t} \) value remains unchanged at \( c_{m,2010} \) through to 2050
- changes in \( c_{m,t} \) from 1990 to 2010 are extrapolated to 2050 with regression analysis to reflect the recent trends

**Forecast of metal consumption, discard and in-use stock**

With future \( F_t \) and \( c_{m,t} \) values estimated in the previous sections, the consumption of each metal for every year until 2050 was calculated using equation (1). A dynamic MFA model was then used to estimate the domestic in-use stock \( (S_{m,t}) \) and discard \( (O_{m,t}) \) for construction using equations (8) and (9).

In the model, the yield ratios \( (y_m) \) were considered because the intermediate metal products (e.g. ingot, plate and bar) consumed at the production and manufacturing process partly turn into a new scrap and therefore will not be contained in the finished products. The ratios for respective metals were set to be: \( y_{Fe} = 0.94, y_{Al} = 0.70, y_{Cu} = 0.83 \) and \( y_{Zn} = 0.92 \) (Daigo, Hashimoto, Matsuno, & Adachi, 2009; Hatayama et al., 2009, 2010; Tabayashi et al., 2009):

\[
S_{m,t} = \sum_t y_mC_{m,t-\tau} \left(1 - \sum_{\alpha = 1}^{\tau} g(\alpha)\right) \quad (8)
\]

\[
O_{m,t} = \sum_t y_mC_{m,t-\tau} g(\tau) \quad (9)
\]

For \( F_t \), three patterns were assumed for future \( a_{sat} \) levels: low \((a_{sat} = 65.2 \text{ m}^2/\text{cap})\), medium \((a_{sat} = 80 \text{ m}^2/\text{cap})\) and high \((a_{sat} = 100 \text{ m}^2/\text{cap})\). For \( c_{m,t} \), constant and variable patterns were considered. These patterns were combined and the results of six scenarios (named \( Lc, Lv, Mc, Mv, Hc \) and \( Hv \)) respectively are shown in Table 1. The amounts of consumption, discard and in-use stock for four metals were estimated for these scenarios.

| Table 1 | Various scenarios for estimating future metal consumption |
|---------|---------------------------------------------------------|
| \( c_{m,t} \) | Constant (2010 value) | Variable (regression) |
| \( a_{sat} \) | \( Lc \) | \( Lv \) |
| 65.2 m\(^2\)/cap | \( Mc \) | \( Mv \) |
| 80 m\(^2\)/cap | \( Hc \) | \( Hv \) |
| 100 m\(^2\)/cap | | |
Results and discussion

New floor area until 2050

Figure 3 presents trends for the floor area $A_t$, calculated from equation (2). In the case of $a_{sat} = 80 \text{ m}^2/\text{cap}$, $A_{2050}$ will be close to the saturation level and reach $73.1 \text{ m}^2/\text{cap}$, whereas in the case of $a_{sat} = 100 \text{ m}^2/\text{cap}$, $A_{2050}$ will be $78.2 \text{ m}^2/\text{cap}$ and will keep increasing with time. However, a decrease in population will drive $A_t$ in a downward turn around 2020 for the $a_{sat} = 65.2$ and $80 \text{ m}^2/\text{cap}$ cases. Of particular note is the scenario in which $a_{sat}$ remains unchanged at 65.2 m², but $A_t$ values decline by 14% from current levels by 2050 ($A_{2050} = 7000 \text{ million m}^2$).

With equation (5) and future $A_t$ values shown in Figure 3, $F_t$ was estimated through to 2050 for each $a_{sat}$ pattern, as shown in Figure 4. In all cases, $F_t$ values decline gradually, after slight increases, by 2030. The increase in the 2020s was attributed to the replacement of buildings built during 1970–90. Even in the case that $a_{sat}$ remains unchanged, $F_{2025}$ was still expected to be 175 million m²/year, or 1.5 times the 2010 level. In the cases that assume growth in floor area ($a_{sat} = 80$ and $100 \text{ m}^2/\text{cap}$), the growth of $F_t$ remained at 170–215 million m²/year, which was lower than that observed during the 1990s.

Metal intensity until 2050

Figure 5 presents the transition in metal intensity $c_{ml,t}$ during 1960–2010 calculated from metal consumption and new floor area (Figure 4 and see Appendix B in the Supplemental data online). In 2010, the metal consumption values per new floor area of steel, aluminium, copper and zinc were 239, 4.08, 1.52 and 0.32 kg/m², respectively. The steel intensity rose modestly from 82 kg/m² in 1960 to 141/m² kg in 2000, and then grew sharply during the 2000s. For aluminium, the increase in intensity was the result of the penetration of the aluminium window frame that lasted until around 1980. While resins are used for more than 60% of window frames in Europe and North America, aluminium or aluminium and resin compounds are used in more than 90% of buildings in Japan (PVC Windows Industries Association, n.d.). However, the intensity remained flat after the spread of the aluminium window frame, despite the development of new uses in interior and exterior products. The copper intensity shows a similar tendency to steel: the increase in the 2000s was remarkable compared with earlier periods. The zinc intensity has been fluctuating, but it seems that there was a peak around 1985 and an inverse-$U$ curve was forming through to 2010. It is likely that the intensity for galvanized steel has also been increasing as well as for other steel. However, it is indicated that the amount of zinc used for galvanizing per unit of steel is declining (Daigo, Osako, Adachi, & Matsuno, 2014). The combination of these two effects is responsible for the inverse-$U$ curve for zinc intensity.

From the changes in $c_{ml,t}$ during 1990–2010, variant $c_{ml,t}$ patterns by 2050 were obtained as per the regression equations shown in Figure 5. In these patterns, metal intensity will increase for steel, aluminium and copper, while declining for zinc.

Metal consumption, discard and in-use stock through to 2050

Based on the patterns of $c_{ml,t}$ and $F_t$ developed above, stocks and flows of steel, aluminium, copper and zinc were forecasted through to 2050 according to the six scenarios shown as Table 1.

Steel (Figure 6)

Steel consumption for the construction sector was 30 Mt/year in 2010, but is estimated at 35–46 Mt/year in future if there is no change in steel intensity. If steel intensity increases in line with current trends, then steel consumption will be 56 Mt/year even for the $L_v$ scenario, and 74 Mt/year for the $H_v$ scenario. If there is no change in intensity ($M_c$ and $H_c$ scenarios), the decline in population will have a larger impact than the increase in per capita floor area, resulting in a declining forecast for steel consumption beginning in 2030. However if $c_{Fe,t}$ is assumed to increase, there is
potential for future increases in steel consumption in the construction sector.

According to the estimation for China by Hu, Pauliuk et al. (2010) and for the world by Pauliuk et al. (2013), steel consumption has a peak around 2025 due to rapid growth in developing countries, followed by a decline until 2050 when replacement demand increases. However, Japan has already passed the peak that still lies in the future for developing countries. Therefore, consumption changes are expected to be modest going forward.

Figure 5  Historical changes in metal intensity with the results of linear regression: (a) steel, (b) aluminium, (c) copper and (d) zinc

Figure 6  Scenario analyses of steel stock and flows: (a) consumption, (b) discard and (c) in-use stock
The steel discard generated by the demolition of buildings and civil engineering structures is estimated to increase to 32–37 Mt/year in 2050. While the differences between the scenarios appear clear for consumption after 2030, the range for discard is not as wide in 2050 due to the long lifetime. The steady increase in discard will result in almost equivalent consumption and discard in the Lc and Mc scenarios in 2050. In these scenarios, the recycling of heavy melting scrap from constructions can make a huge contribution to reducing the primary production of steel.

In the Hv scenario, in-use stock in 2050 is estimated to increase to 2.2 billion tonnes from 1 billion tonnes in 2010. In the Lc scenario, neither \( a_t \) nor \( C_{Fe,t} \) changes, but future \( C_{Fe,t} \) is significantly larger than \( C_{Fe,t} \) before 2010 (Figure 5(a)), which results in the increase in steel stock by replacement. In 2050, most of the stock will consist of building and civil engineering structures built in the future. Therefore, in order to make effective use of secondary resources when this enormous stock is scrapped after 2050, it will be necessary for the stock to be in forms that enable easy recovery and recycling of steel at the time of demolition.

**Aluminium (Figure 7)**

As a slight change was assumed by regression analysis in \( c_{Al,t} \) in the future, the results for the constant and variable \( c_{Al,t} \) scenarios are similar. Although aluminium consumption has been in decline since the 2000s, it will remain at 600–820 kt/year, slightly higher than 2010, due to a future increase in demolished area.

Discard was estimated to double from 250 kt/year in 2010 to 500–550 kt/year in 2050. Besides the old scrap indicated in Figure 7(b), new scrap is generated during production and manufacturing processes. The process yield ratio of aluminium extrusions used as building materials is relatively low; hence, it is assumed that 30% of consumption \( C_{Al,t} \) is generating new scrap. In 2050, the sum of old and new scrap will thus exceed consumption. For building materials, magnesium and silicon-rich 6xxx alloys are mainly used. Closed-loop recycling of these alloys as building materials is feasible if contamination with other elements such as iron and zinc is prevented. However, scrap composition needs to be adjusted for other uses. An open-loop recycling system across different uses must be prepared with technology development to utilize the scrap surplus in the construction sector.

In the Lc scenario, the in-use stock will not change significantly from 18 Mt in 2010. Even in the Hv scenario, the in-use stock in 2050 is estimated at 23 Mt. There has been no significant change in \( c_{Al,t} \) during 1990–2010 (Figure 5(b)), whereas \( C_{Fe,t} \) has increased significantly in the past 20 years. Therefore, stock increase induced by replacement was not observed for aluminium.
Copper (Figure 8)
Copper intensity has been growing since 1990 as with the case for steel. Therefore, future trends for consumption and discard are similar to those for steel. However, while there was gradual and continuous growth in steel intensity during the 1960–90 period, copper was either flat or slightly in decline (Figure 5(c)). Therefore, the influence of future replacement on stock increase is discreet in the Lc scenario. In the variable $c_{Cu,t}$ scenarios, however, in-use stock will increase to 11–14 Mt from 7.1 Mt in 2010.

Zinc (Figure 9)
Consumption for construction use was 40 kt/year in 2010, and was forecasted to be 46–61 kt/year in the Lc, Mc and Hc scenarios. In the Lv, Mv and Hv scenarios, the intensity was assumed to decline, which leads to a decline in consumption beginning around 2025. Zinc consumption in these scenarios was estimated at 26–33 kt/year in 2050. Discard was estimated at 48–57 kt/year in 2050, where increase in the zinc discard from 2010 to 2050 for the Lc scenario was also more modest than for other metals.

In-use stock was 2.3 Mt in 2010 and did not significantly change in the Mc and Hc scenario. For other scenarios, it declined to 1.4–1.9 Mt. Of particular note are the scenarios with variable intensity, in which $c_{Zn,t}$ was roughly halved from the 1980–90 levels. In those scenarios, future in-use stock decreased because of the use of galvanized steel having a lower zinc intensity.

Zinc coating works as a sacrificial material to prevent steel corrosion, and it is thus partly dissipated into water or soil during use. As the dissipation was neglected in this study, the amount of in-use stock and discard in Figure 9 might have been overestimated. The MFA study on zinc by Tabayashi et al. (2009) estimate 94 kt/year of sacrificial loss from the domestic zinc stock in 2005, which is roughly triple the year’s discard. Conversely, Odnevall Wallinder, Verbiest, He, and Leygraf (1998) report that zinc loss during use occurs at a low rate. It is thus difficult to know how much potential exists to recover zinc via recycling of galvanized steel. However, zinc consumption in the construction sector was 40 kt/year in 2010, which did not take a prominent part of the total zinc consumption of 600 kt/year. For reduction in primary zinc production, it is also important to regard recovery from other products such as machinery and automobiles.

Impact of individual factors on stocks and flows
Figures 6–9 clarify the impact of changes $a_{sat}$ and $c_{m,t}$ on metal consumption, discard and in-use stock for the construction sector.

Future $F_t$ was calculated from three $a_t$ patterns. Although the range of $a_{sat}$ was set broadly, 63.2–100 m²/cap against $a_{2010} = 65.2$ m²/cap, $F_t$ fluctuated within historical levels in all cases. Thus, the level of per capita floor area will not greatly affect the volume of metal consumption in the construction industry by 2050. In calculating $F_t$ and $D_t$ from $A_t$ using equations
(2) to (5), another factor was the lifetime of the constructions. The sensitivity of the average lifetime has been examined in several studies that forecast the long-term change in building stocks (Bergsdal et al., 2007; Hu, Bergsdal, van der Voet, Huppes, & Müller, 2010; Müller, 2006). As there has been already a considerable amount of in-use stock in Japan, the sensitivity of \( g(t) \) may be relatively small. Nevertheless, the analysis would be significant in evaluating Japan’s challenges toward a stock-centric society (Ministry of the Environment, 2014, p. 12).

A distinctive feature for Japan is the decline in population, which is forecast to be 14% smaller in 2050 than in 2010 (Table A2 in the Supplemental data online). Although increases in floor area have been found to be consonant with population growth, it is not clear whether a population decline will similarly induce a decrease in the building stock. Furthermore, future changes in the demographic structure could change the number of persons per dwelling, as simulated by Bergsdal et al. (2007). This would affect the size, configuration and type of dwellings (particularly to accommodate the specific needs of the elderly and also to accommodate the changing size of households). This would lead to a change in metal demand for these buildings. Monitoring these points can provide useful insights for Japan’s and other countries’ construction industry to adapt to an aging society.

The metal intensity would have a greater impact on the metal cycle than the saturation level of the floor area. Steel and copper intensities have grown over the past 20 years, which may significantly increase future consumption. An increase in metal intensity can grow the in-use stock even when floor area declines because demolished buildings are likely to be replaced with higher intensity buildings.

By means of decomposition analysis, this study identified the significant contribution of metal intensity on metal stocks and flows. The decomposition analysis could evaluate the impact of technology changes that would take place in building and civil engineering projects. For example, as the use of resin for window frames expands in Japan, the aluminium intensity will decrease. The introduction of Home Energy Management Systems (HEMS) and Building Energy Management Systems (BEMS) may enhance the copper intensity in the construction industry. Although the zinc intensity in galvanized steel keeps decreasing (Daigo et al., 2014), a limit to this reduction may be reached in future. A linear regression of metal intensity \( \epsilon_{int} \) used in this study is a very simple method. The impacts of those technology changes on the metal cycles can be evaluated if the intensity changes are adequately determined.

**Conclusions**

This study presented the outlook of metal consumption for building and civil engineering projects toward 2050 for steel, aluminium, copper and zinc. The new floor area and the metal intensity per unit new floor area...
were used as the factors assumed to contribute to annual metal consumption. Future patterns of the factors were envisaged from the time-series changes. Finally, consumption, discard and in-use stock through to 2050 were estimated for six scenarios for the respective metals.

According to the three saturation values assumed for per capita floor area, the new floor area was forecasted to be in the range of 146–192 million m²/year. The new floor area began to decline in 2005, but is expected to be higher than 2010 levels in future as buildings built during the 1970–90 period are demolished and replaced. However, it would not increase to the levels of around 1990.

Trends for metal intensity during 1960–2010 differed significantly among the four metals. While the steel and copper intensities increased from their values in the 1990s, the aluminium intensity remained flat from the 1980s after the spread of aluminium window frames. The zinc intensity declined for a couple of decades because of improvements in the galvanizing process.

Many past MFA studies have been clarifying the amounts of flows and stocks within the metal cycles in a specific industry, country or global level. The methods and results assisted the decision-making processes on resource management, waste management and environmental management for stakeholders. This study provided new information for exploring resource management from a long-term perspective. In particular, decomposition of metal consumption for the construction sector clarified the different trends of intensities among metals. The analysis is expected to be used for evaluating how new technologies affect the metal cycles.

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**Supplemental data**

Supplemental data for this article can be accessed at http://dx.doi.org/10.1080/09613218.2014.975427

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