Urban Mining:
The City as a Source for Re-usable Building Materials

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Abstract: The general idea of this paper is the attempt to extend the idea of "urban mining" to construction, regarding the city as a huge source of different types of re-usable building materials. The author firstly develops a methodology to estimate the accumulated resources in Japanese building stock using the presumed building stock distribution as well as a database of itemization of major structural materials per floor area categorized by different constructed year and building types. The result shows that huge potential recourses are accumulated in the Japanese building stock at year 2002, which is including 643 million tons of steel, 715 million m3 of wood and 3384 million m3 of concrete. Compared with the demand in general use of those materials, the importance to create new possible demands emerges, such as the recycled aggregate for concrete and the biomass-use for wooden materials. Secondly the connection between open building and urban mining is discussed. It is concluded that the open building approach can increase the resource-use efficiency; particularly in case of a well–developed infill system is good for the circular use of materials in building. The result of this research could provide an important reference for future strategy making.

Keywords: urban mining, building stock, open building, recycling use of resource

1. INTRODUCTION

Waste generated within cities has recently been regarded as a very important mean for generating new resources. The term "urban mining" is used to respond to this issue. According to this concept, a city could be considered as a huge stock consisting of many resources. With arising environmental concerns, it becomes very urgent to realize the actual quantities and the formation of building stock in order to utilize resources more efficiently. For that reason the author first develops a methodology to estimate the accumulated resources in the building stock within a case study area. Secondly, potential solutions are suggested by looking at the balance of demand and supply of these resources. Thirdly, the potential benefits of the open building approach are discussed.

2. URBAN MINING

The word 'Urban Mining' is created in the late of 1960s'. It was generated from the perspective of environmental concerns by recycling of various wastes, scraps and garbage. By recycling of diverse industrial products in the city, many valuable and useful materials can be obtained. Compared to natural mining, it is more efficient to get certain important materials through urban mining in the city. As an example, by refining 1 ton of cell-phones 280g of gold and

1.89kg of silver can be extracted, while only 10g of gold can be extracted from 3 tons of overburden in natural mining.

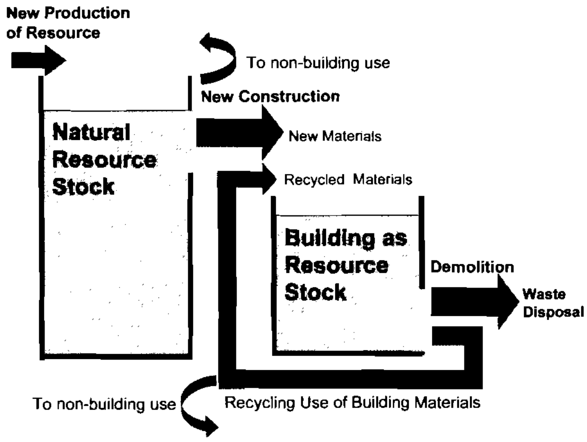

Fig.1 Diagram of metabolism of material use around buildings (Yashiro, 2001)

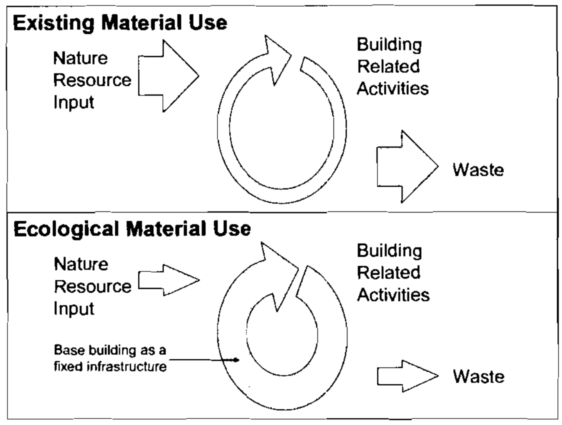

Fig.2 Concept of ecological material use (Yashiro, 2001)

Shimoda (2001) addressed that more than half of the resources consumed in a city per year are accounted to the construction sector, and most of these resources are accumulated as building stock. With arising environmental concerns, it becomes very urgent to realize the actual quantities and the formation of building stock in order to utilize resources more efficiently.

Figure 1 shows the concept of the resource-use in the construction field. The diagram depicts two big tanks, one is the natural resource stock, and the other is the building stock. Every year a certain amount of virgin material flows from the tank of the natural resource stock to the tank of building stock through the construction of new buildings. On the other hand, a certain amount of building material also flows out from the tank of building stock through demolition of buildings, of which some of it is recycled and some of it becomes waste. In the concept of 'ecological material use' (fig.2, Yashiro, 2000), it is aimed at minimizing both the new resource use from the natural resource stock as well as the waste generated from building demolition. In this point of view, if the building can be used for a long time as a fixed infrastructure, it is possible to reduce the resource consumption as well as the waste generation, that is, the improvement of resource efficiency. However, it is very difficult to satisfy the ever changing demands of the users towards the building. According to Yoshida's research (1996), the prevailing reason for demolition of building accounts for social or economic factors, but mainly not physical factors of the building itself. To solve this problem, a continuous customization system is necessary. The open building approach has a good adaptability to deal with this problem. With the replacement of the infill system, the base building (equivalent to a fixed infrastructure) can be used for a long period. Later this will be referred to the concept of open building again.

In general, it can be stated that a city is a huge mine. Every year a certain amount of buildings is demolished and that is accompanied by producing many solid wastes, including wooden, steel and concrete materials. However, those wastes can be regarded as re-usable materials in a positive way. Although, the construction industry generates a huge amount of waste every year, there is a high potential capacity for the reuse of these materials. Particularly after the enforcement of the 'Regulation of Recycling in Construction' in 2002, the classification and proper treatment of those construction wastes has become the responsibility of the owner of the demolished building. For this reason, it is easier to access those potential materials.

To use these hidden resources more efficiently, it is very important to realize the quality and the quantity of these accumulated resources. However, there is no proper methodology to estimate the quantities of those potential materials. The author proposes a methodology to response to this problem. Two kinds of information are required for the estimation:

1) Quantity and formation of the building stock

2) Materials used per floor area according to different building types.

The details are described in the following paragraphs.

3. ACCUMULATED RESOURCES IN THE BUILDING STOCK

3.1 Methodology to estimate the accumulated resources in the building stock

In this paper, the quantity of resources accumulated in the building stock at t year $Q(t)$ is defined as follows:

$$Q(t) = S(t) \times U(t)$$

where $S(t)$ is the amount of the building stock at t year, $U(t)$ is the basic unit of major building materials consumed per floor area at t year.

3.2 Quantity of the major materials consumed per floor area (basic unit)

The 'Survey on actual conditions of construction materials and labor' is held by the Ministry of Construction in Japan every 3 years since 1976. The quantities of major materials consumed per floor area (basic unit) of different structural types / functions of buildings are calculated and published. The result of this survey can be regarded reliable as 5000 samples are extracted among the building work sites in each survey year. The author accessed the data from 1976 to 2000(the newest version) and 4 major building materials are picked up as a basic unit for estimation. Since the survey is held every 3 years, the data of the survey year is regarded as a standard value and extended to the other 2 years. The basic unit before 1976 is assumed as the value of 1976.

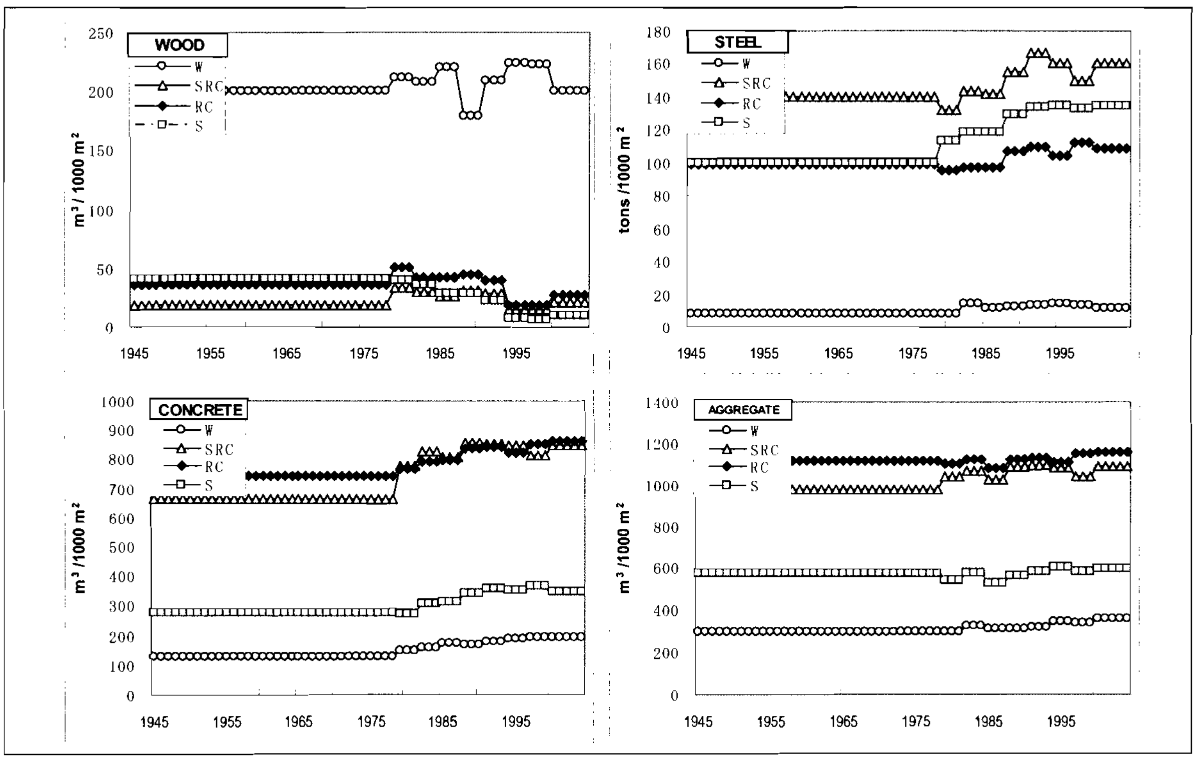

Fig.3 Fluctuations in the quantity of major materials used per floor area in different structure types

Figure 3 shows the fluctuations in the quantity of major materials used per floor area in different structure types, where 'W' means wooden structure building, 'SRC' means steel reinforced concrete structure building, 'RC' means reinforced concrete structure building and 'S' means steel structure building. As the diagram indicates, the use of concrete and steel has an increasing trend in all kinds of structure types. It can be explained by the improvement of technologies and the requirement for higher structure strength. Besides, the use of wooden materials in wooden structure building had a fluctuating change while the other structure types were on the decrease.

3.3 Building stock distribution by constructed year

To estimate the potential accumulated resources in the building stock, it is very important to have a clear grasp of the actual building stock itself. In Japan, though there is not plenty of statistical data about the building stock existing, the record for 'Fixed Property Tax' is one of the most reliable information sources to represent the reality of the building stock. However, in this record, only the quantity of current existing buildings is shown but the information of the constructed year is not listed.

Though it is possible to make a rough estimation by only using the quantity of current existing buildings, a more accurate result could be expected if we can realize the building stock distribution by constructed year. To overcome this problem of the missing information, a methodology proposed by Yashiro (1996) is introduced. For this the flow data based on the 'Building Construction Survey' as well as the life distribution model of buildings are applied. The details of this method are listed as following.

The buildings are classified by constructed year while the amount of each cohort decreases by time. The decreasing rate of buildings $R(t)$ is defined as following:

$$R(t)=1-\int_0^t f(u)\,du$$

Here $R(t)$ is the remainder function and $f(u)$ is the probability distribution of the life of buildings.

To simplify the discussion of this model, the difference of the remainder function in different cohorts is ignored as an assumed condition. In this case, at the point t year, the amount of existing buildings constructed in k year $S_k(t)$ can be shown as following.

$$S_k(t)=S_k(0)\times R(t)$$

Here $S_k(0)$ shows the quantity of new constructed buildings at k year.

Further, since the accessible flow data based on the 'Building Construction Survey' started from 1946, buildings constructed before 1945 are regarded here as a different group using a different remainder function.

$$S_{prewar}(i)=R_{prewar}(i-1945)\times S_{prewar}(1945)$$

Where $S_{prewar}(i)$ is the amount of building stock constructed before 2nd World War in i year, and $R_{prewar}(i-1945)$ is the remainder function of the stock of buildings constructed before 2nd World War, based on the amount of existing buildings in 1945.

Further, according to previous research (Yashiro, 1994), $R_{prewar}(i-1945)$ could be represented by a logistics curve as follows:

$$R_{prewar}(i-1945)=k/\left(1+\exp\left(b+a\times(i-1945)\right)\right)$$

The parameters of this formation could be defined as following: (Yashiro, 1996)
K=1.0195, *a*=0.12422, *b*=-4.45

According to a series research on the life span of buildings (Yashiro, Komatsu, Kato, and Yoshida, 1990), using terms of reliability theory, the 'probability density function of failure' is supposed to follow a normal distribution or logarithmic normal distribution from graphic analysis and as a consequence in this paper a normal distribution function is applied and the parameters are as following:

$$R(t)=1-\frac{1}{\sqrt{2\pi}}\int_0^t \exp\left\{-\frac{(x-\mu)^2}{\sigma^2}\right\}dx$$

where $\mu = 40.55$, and $\sigma = 10.23$

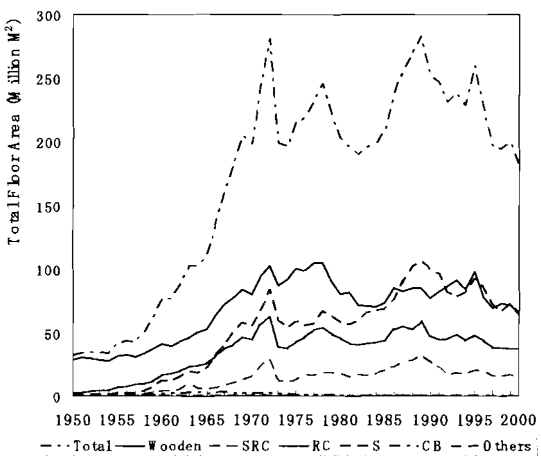

Fig.4 Flow data of Japanese building construction

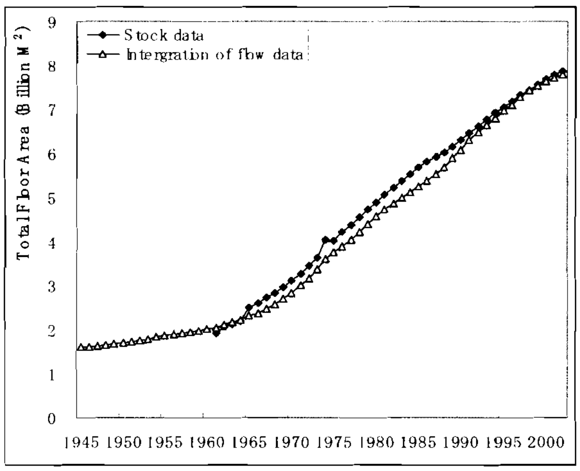

Fig.5 Comparison by the integration of flow data and actual stock data

Figure 5 shows the result of comparing integration of total floor area of survived buildings constructed in the past with the total area of actual existing buildings using flow and stock data from the 'Building Construction Survey' and the property tax registration. Here the result shows that presumed data is very close to the actual situation.

Figure 6 shows the supposed distribution of the present Japanese building stock by constructed year. It displays that most of the present Japanese building stock is occupied by buildings constructed after 1970. It illustrates the fact that the Japanese present building stock has been formed very rapidly within the last 30 years. Now as buildings constructed in this period are aging, they might represent a big issue in the future. Strategies to respond to this problem are very important.

Figure 7 shows the transition of potential resources accumulated in the Japanese building stock based on the result of the presumed distribution of the building stock by constructed year. The rapid growth since 1970 of 3 kinds of main building materials can be observed. Only the use

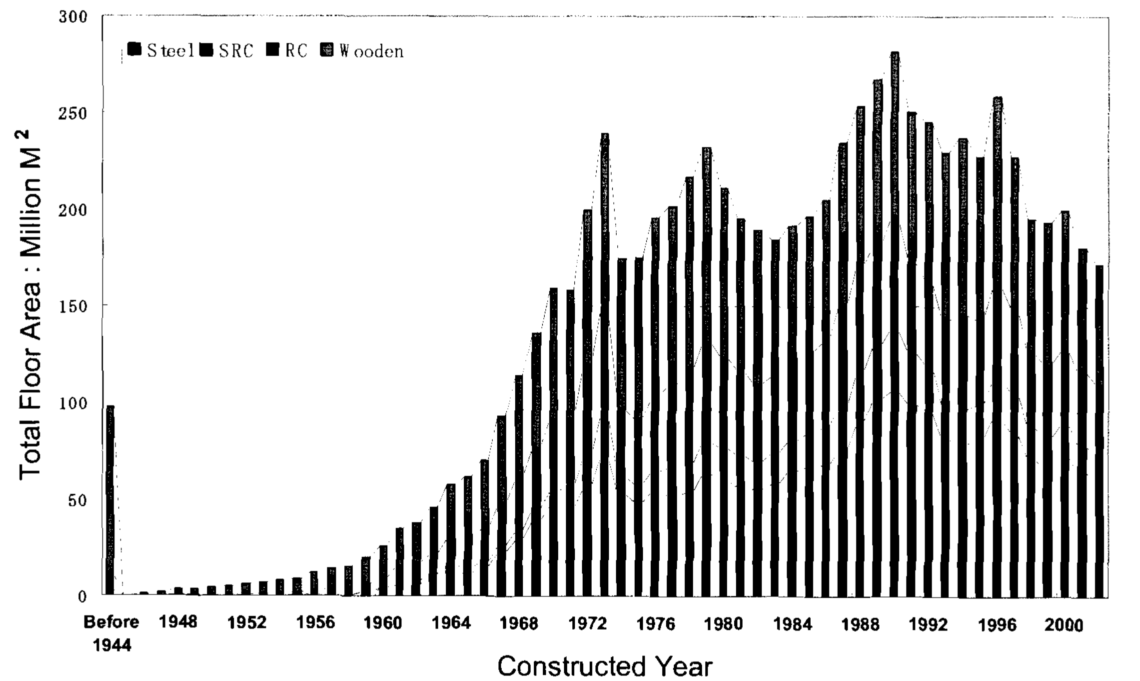

Fig.6 Presumed distribution of Japanese building stock by constructed year at 2002

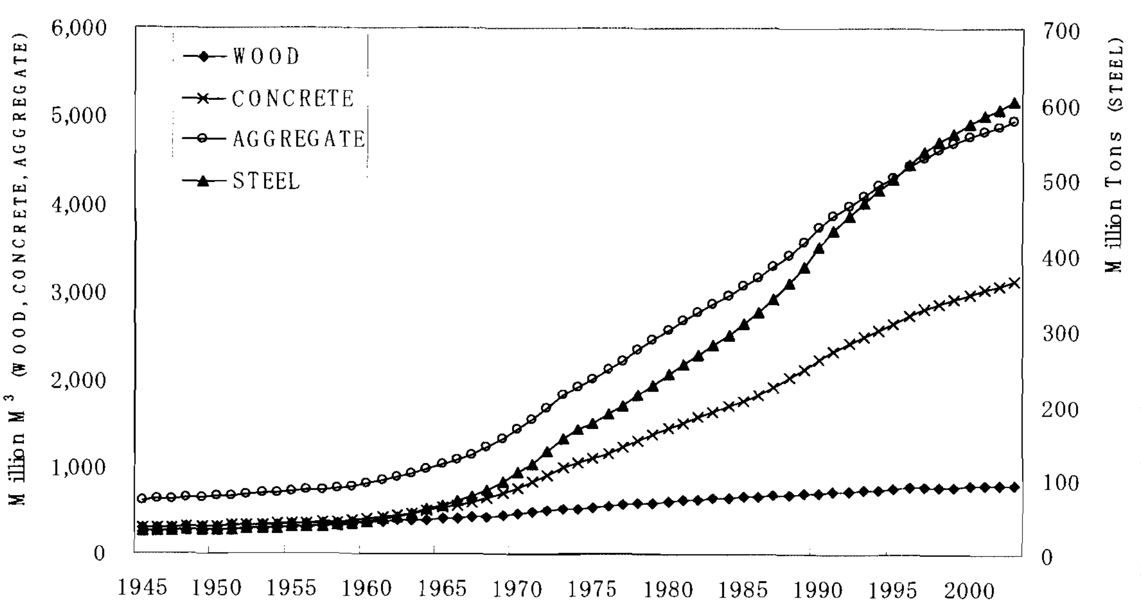

Fig.7 Transition of potential resources accumulated in the Japanese building stock

of wooden materials grows slowly and is leveling off. It can be explained by the share of wooden structure buildings as well as the use of wooden materials in building is decreasing.

3.3 Result of estimation

According to the result of the estimation, the accumulated resources in the Japanese building stock are shown in table 1 and the detailed descriptions are as follows:

Table 1 Potential materials accumulated in Japanese building stock in year 2002

MATERIALS	WOOD	STEEL	CONCRETE	AGGREGATE
QUANTITY	715,463,430 (m^3)	643,018,694 (tons)	3,384,288,433 (m^3)	5,172,790,610 (m^3)

1) Wood:

715 million m3 of wooden materials are accumulated in the Japanese building stock. This is 7 times as much as the annual consumption of wooden materials in Japan; 40 times of the demand of wooden materials in the Japanese building sector in 2000 (17 million m3). It is clear that the accumulated resources are huge and potential. However, since the imbalance of demand and supply, it is important to create new possible demands such as the particle boards for interior finishing materials as well as the biomass-use for energy.

2) Steel:

643 million tons of steel materials are accumulated in Japanese building stock. This is about 25 times of the annual consumption of steel materials in Japanese construction sector (26 million tons). Since steel is a high value materials as well as the recycling route for it is well-developed, the recycled rate is very high. However, if a huge amount of steel scrap released from the demolished buildings in the near future, problems might occur because of the imbalance of demand and supply. Further, impurities in the steel scrap are also a bottle neck for the recycling of steel.

3) Concrete:

Compared with the demand for roadbed materials (the major use of concrete scrap currently) per year (35 million tons), 3384 million m3 (7783 million tons) of concrete are accumulated in the Japanese building stock. Though the demand is decreasing while the amount of demolished reinforced concrete buildings is increasing, it is very urgent to create some other use of these materials. For instance, used as aggregate (recycled aggregate) in fresh concrete, a big demand can be obtained. That is about 40 times of today's demand for the roadbed materials per year. For that reason the Japanese government is now making the amendment for the regulations to implement this use of recycled aggregate.

4. OPEN BUILDING APPROACH AND URBAN MINING

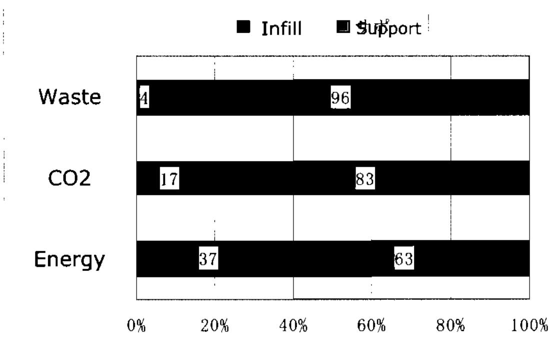

Fig-5 Contents of resource used categorized by Infill and Support (based on the survey on the demolition of a 3DK type housing unit) (WENG, 2001)

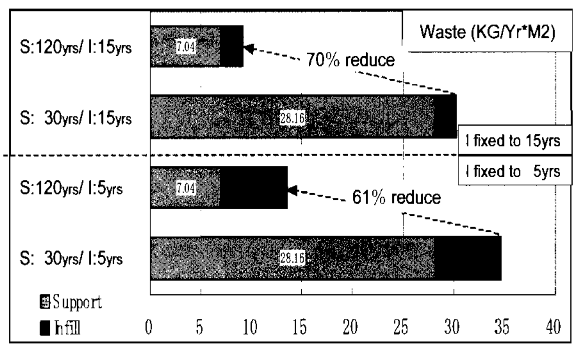

Fig-6 Effect on reducing waste generation by extending the life time of the base building (based on a 3DK type housing unit) (WENG, 2001)

According to the author's research (WENG, 2001), the open building approach describes a useful contribution to the resource-use. 61% to 70% solid waste could be reduced by extending the life span of buildings from 30 years to 120 years (figure 6) and this result illustrates the potential advantage of the open building approach for the environmental aspect to reduce the consumption of resources. As the concept of 'ecological material use' mentioned above shows, if buildings (skeleton or support) can be regarded as a fixed infrastructure, both the input of new resources as well as the output of wastes could be reduced.

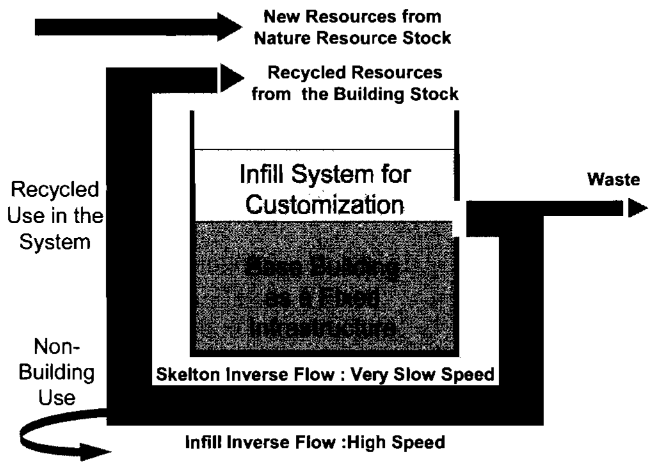

Fig. 7 Connection of the open building approach to urban mining

Figure 5 shows the contents of resources used categorized by Infill and Support (based on the survey on the demolition of a 3DK type housing unit) and it becomes clear that materials used in the support (skeleton) accounts for a very large share in the weight of the whole system. However, materials which have high embodied energy are frequently used in the infill level. Since the replacement of infill will be more frequent in the open building approach than the traditional, it is very urgent to develop a recycling system for the infill not to cause additional negative impact on the environment. On the other hand, if the re-use / recycling system can be well-developed, more efficient route for recycling could be expected.

Figure 7 illustrate the connection of the open building approach to urban mining. The bottom of the tank is the fixed infrastructure consists of base building. The accumulated resources here will flow out very slowly because of the long-tern use for those building. On the other hand, at the top of the tank, infill systems are replaced frequently to meet the customer's ever-changing needs. Although the speed of flowing out will be faster, the recycling system can conduct a well circulation for the utilization of resources

5. CONCLUDING COMMENTS

In this paper, the concept of 'Urban mining' is addressed and a methodology for estimating the potential resources accumulated in the building stock is proposed.

The methodology developed in this paper need to be more discussed. Mathematical formula indices presented in this paper are supposed to be applicable to express building stock formation. However, more precise mathematical expressions and intensive analysis is needed. Especially this is necessary for the discussion of the difference of the remainder function in different cohorts of different construction years and regions.

The result of the estimation shows that a huge potential of resources is accumulated in the Japanese building stock. At year 2002, 643 million tons of steel (which is about 25 times that of the annual consumption of steel materials in Japanese construction sector (26 million tons)), 715 million m3 of wood (which is 7 times as many as the annual consumption of wooden materials in Japan) and 3384 million m3 of concrete (220 times of concrete scrape generated per year in Japan) are accumulated in the building stock. Compare with the demand in general use of those materials, the importance to create new possible demands emerges, such as the recycled aggregate for concrete or particle boards for interior finishing materials as well as the biomass-use of wooden materials.

The connection between open building and urban mining is also discussed, it is concluded that the open building approach can increase the resource use efficiency. Two benefits can be pointed out:

1) Long-term-use of the base building can keep the resources accumulated in the stock.

2) Close-cycle infill systems are efficient for the recycling of fitting-out materials in buildings

The author finally suggests that the following issues should be discussed in the future

1) Methodology to grasp the quantity and quality of recyclable building materials

2) Policies to enforce the motivations for using those recycled materials

3) Supply chain management for inverse logistics

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