 ISBN: 9789052693958

SUSTAINABLE CONSTRUCTION FOR INDUSTRIALIZED DETACHED HOUSE ROLE OF RESOURCE RECYCLE FACILITY

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Abstract
The objective of this research is to analyze the function and effects of resource recycle facility in a Japanese industrialized detached house manufacturer. First, this paper analyzes the actual condition of waste disposal before the establishment of resource recycle facility. Secondly, this describes the logistics of the facility, and surveys the actual condition of waste separation with the facility. Thirdly this makes clear of the site fabrication of plaster board, and shows the trial calculation of material flow cost accounting for plaster board. Finally, this discusses the effectiveness of the facility established by house manufacturer itself.

Keywords: detached house, industrialized house, resource recycle, industrial waste disposal, waste separation

INTRODUCTION

The industrialized house is a house which applied an advanced industrial technology to the production. In Japan, the effectiveness of the applied technology has been demonstrated. However, the difference of productivity among construction projects is pointed out (Wu et al., 2008). Construction sites in the central area of Tokyo are small. There are no stock yards at construction sites. A general contractor is starting to adopt a little collection of industrial wastes from small projects (Hamada et al., 2004). The comprehensive logistics for detached house projects is necessary. Moreover, global environment problem has been more important. Some industrialized detached house manufacturers have set up resource recycle facilities for the establishment of resource recycle system.

Objectives

The main objective of this research is to analyze the actual function and effect of resource recycle facility in a Japanese industrialized detached house manufacturer, and to propose the comprehensive and efficient resource recycle system from the standpoint of economic and environmental assessment. This research surveys the kinds of waste separation and their quantities at construction sites to make clear the effort at sites for industrial waste disposal. Then, this surveys the waste separation and the recycle system at resource recycle facility and analyzes the effectiveness of the facility established by house manufacturer itself.

Research Method

This research compares the former industrial waste disposal system and the current industrial waste disposal system with resource recycle facility of house manufacturer M. First, this surveys 4 construction projects as the former system, and makes clear the kinds of waste separation and their quantities at construction site. How to dispose industrial waste outside construction sites is also surveyed. Secondly, this analyzes the operation results of the resource recycle facility built in 2009 as the current system, and makes clear the relation between site fabrication and waste quantity of plaster board. Finally this discusses the role and function of resource recycle facility established by the house manufacturer itself.

WOOD PANEL BONDING STRUCTURE AND CONSTRUCTION METHODS

Wood panel bonding structure

The house manufacturer M in Japan has built the industrialized houses on the basis of Japanese industrialized system. Figure 1 shows the structure of wood panel bonding method by house manufacture M. The structure of house is mainly composed of floor panels, wall panels and roof panels. The panels are manufactured in the factory beforehand, and are joined with glue at construction sites. Nailing and screwing is necessary as a finishing operation. After the shell of the building with the panels is erected, the desired finishes are applied to both inside and outside. On the outside, the plywood is often covered with the siding. On the inside, the fabric is often applied.

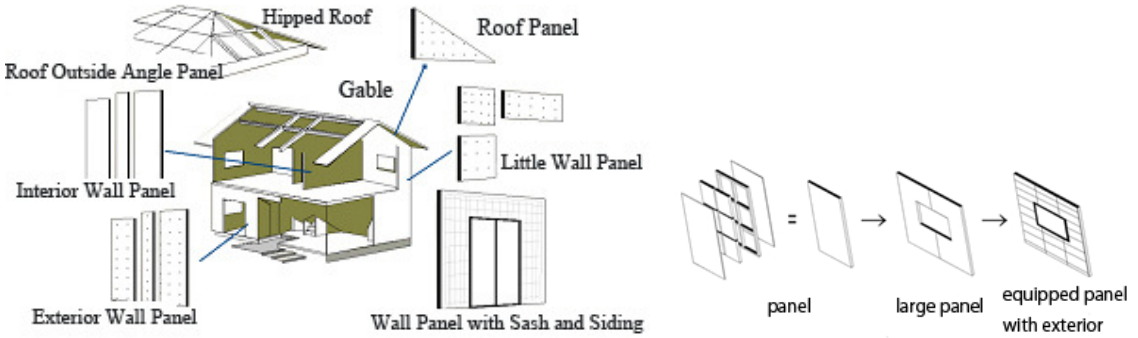


Figure 1: *Wood panel bonding structure*

Factories for wood panels and components manufacturing in Japan

The left in the figure 2 shows the location of factories of house manufacturer M in Japan. They are scattered and covers the whole area of Japan. The survey of delivery of materials from the factories investigates the distance and packing methodology of building components (Kimoto, 2009). The standard number of times of delivery by the house manufacture is 3. The objects in the first delivery are wood panels of main frame. Those in other deliveries are interior and exterior finishing building components.

The right in Figure 2 shows the location of resource recycle facility. It is established in the center of Kanto area which is comprised of 8 prefectures including Tokyo in 2009.

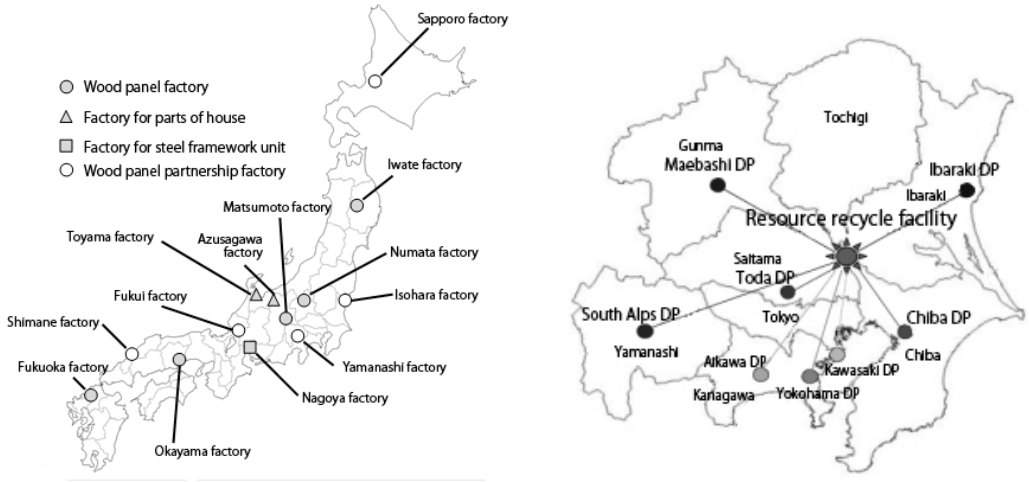


Figure 2: *Location of factories (left) and resource recycle facility (right) in Japan*

Various kinds of construction methods from the standpoint of prefabrication

In the delivery of wood panels, the adoption of pre-assembly at factory is a matter for study. Some projects adopt the pre-assembly of wood panels with the siding at factory. The left in figure 3 shows the pre-assembly of wood panels. The other projects can not adopt the pre-assembly because of small construction sites and narrow access roads. The right in figure 3 shows the delivery of wood panels. They assembled wood panels at construction sites. The adoption mainly depends on the condition of access roads. A big truck cannot run on narrow roads. A crane cannot work on narrow roads. The pre-assembly can reduce the workload at site. The supplies from the house manufacturer are relatively long-distance migration. On the other hand, the elective components by clients are relatively short-distance migration.

Figure 3: *Pre-assembly at Factory (left) and Assembly at Construction Site (Right)*

WASTE DISPOSAL WITHOUT RESOURCE RECYCLE FACILITY

Waste separation at construction sites

The survey of the collection of industrial wastes from construction sites to waste disposal facilities investigates the waste separation and the waste quantity. The survey, based on questionnaire with 25 dealers beyond the scope of resource recycle facility, makes clear the

actual condition of waste disposal. Figure 4 shows the main number of waste separation. They are different. There is one dealer that separates 10 kinds of waste. There are three dealers that don't separate waste at construction sites. There are six dealers that separate 2 kinds of waste. Figure 5 shows the main items of waste separation. Over 70 percent of dealers adopt the separation of plaster board. Nearly half of dealers adopt the separation of chips and shavings, and cardboard.

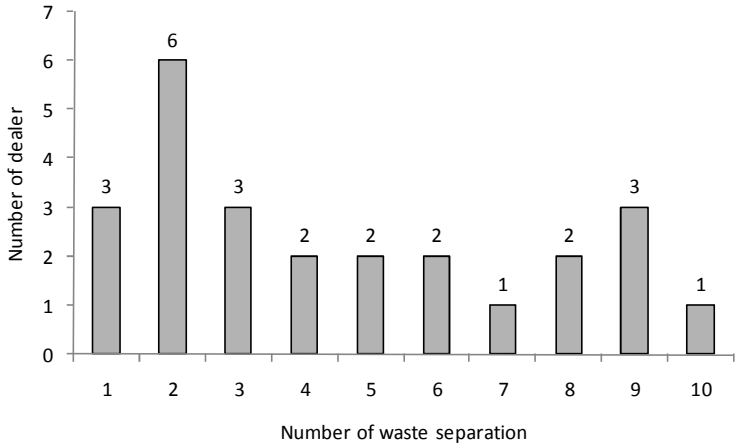


Figure 4: *Number of waste separation*

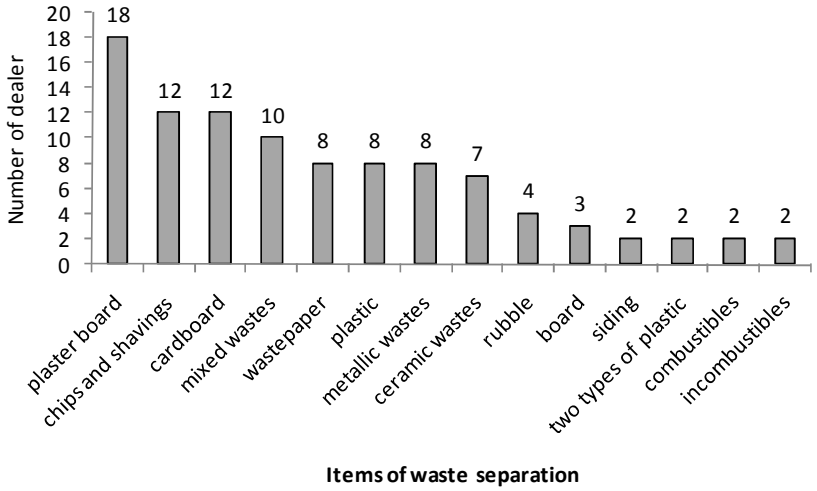


Figure 5: *Items of waste separation*

Volume of industrial waste from construction sites

Table 1 shows the construction projects for survey of industrial waste disposal before the establishment of resource recycle facility. They are located at Tokyo and the neighboring prefecture in Japan. They are detached houses, and wood panel build 2-storied structure. The size of houses is similar. S1 and S2 adopt the pre-assembly construction method of wood panels. M1 and M2 adopt the site-assembly construction method of wood panels. They carry industrial waste to intermediate process facilities. Their function is mainly the separation of wastes and the disposal of some parts.

Table 1: *Construction projects for survey*

Project	S1	S2	M1	M2
Location	Kashiwa City, Chiba, JAPAN	Kashiwa City, Chiba, JAPAN	Kita Ward, Tokyo, JAPAN	Itabashi Ward, Tokyo, JAPAN
Number of Stories	2	2	2	2
Site Area	260 ㎡	150 ㎡	100 ㎡	80 ㎡
Total Floor Area	115 ㎡	120 ㎡	105 ㎡	85 ㎡
Entresol Area	-	-	30 ㎡	20 ㎡
Construction Period	August, 2007 - September, 2007	July, 2008 - September, 2008	October, 2007 - December, 2007	May, 2008 - July, 2008
Structure	Wood Panel Bonding Method			
Site Condition	Good for Construction		Bad for Construction	
Assembly of Wood Panels	Pre-assembly of Wood Panels with Siding at Factory		Assembly of Wood Panels at Construction Site	
Number of Delivery	3	3	3 (Every Day)	5

Table 2: *Waste disposal at construction sites before the settlement of resource recycle facility*

	Number of Separation	Item									Total
		Plastic	Chips and Shavings	WastePaper	Cardboard	Fiber Waste	Plaster Board	Metallic Wastes	Concrete	Ceramic and Glass	
S1	4	-	○ 2.00㎥	○ 5.00㎥	-	-	○ 1.00㎥	-	-	○ 0.20㎥	8.20㎥
S2	5	○ 0.50㎥	○ 6.50㎥	○ 3.50㎥	-	-	○ 0.50㎥	-	-	○ 0.50㎥	11.50㎥
M1	9	○ 0.20 t	○ 0.86 t	○ 0.15 t	○ 0.27 t	○ 0.30 t	○ 1.52 t	○ 0.07 t	○ 0.15 t	○ 0.09 t	3.61 t
M2	6	○ 0.55 t	○ 0.80 t	○ 0.41 t	-	-	○ 1.40 t	○ (Metal) 0.06 t	-	○ (Glass) 1.78 t	5.00 t

Table 2 shows the actual waste separation and waste quantity of 4 projects at intermediate process facilities. The numbers of waste separation are different: 4 in S1 project, 5 in S2 project, 9 in M1 project, and 6 in M2 project. The intermediate process facilities in S1 and S2 measure the volume of industrial waste. The ones in M1 and M2 measure the weight of industrial waste. It depends on their systems. House manufacturers had not made effective use of the results.

RESOURCE RECYCLE FACILITY

Role of Resource recycle facility

In 2009, house manufacturer M established the resource recycle facility by itself. The expected role of the facility is to grasp the actual condition of industrial waste disposal and improve the environmental management system including the logistics and the effective utilization system of resource. It is important to grasp the actual condition of returned goods. The establishment of feedback mechanism about the above information is also important.
The facility adopts the QR code system to grasp the waste separation and waste quantity accurately and quickly. Figure 6 shows an example of QR code attached at construction site for industrial waste. It has the project information. The industrial waste at construction sites are separated to 10 kinds shown in figure 6.

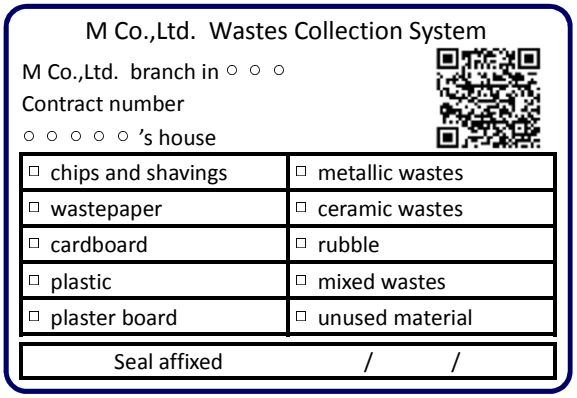


Figure 6: *QR code system at resource recycle facility*

Advantageous effect of logistics by resource recycle facility

Figure 7 shows the before and after comparison of logistics of house manufacturer M. After the establishment of resource recycle facility, 10 ton trucks go around among the distribution center, the deposit center and resource recycle center. 2 ton trucks go around among the deposit center and construction sites. Special common pallets for both the delivery of materials and the collection of industrial waste are used over and over again. As a result, the material flow has rationalized.

Figure 8 shows the ratio of industrial waste collected to the resource recycle facility from May 2009 to September 2010. The ratio of plaster board and ceramic wastes is 26 % and is the highest. That of chips and shavings is 16 %. That of cardboard is 11 %. The ratio depends on the structure and specifications of houses.

Figure 9 shows the time series data of quantity of industrial waste brought from construction sites from May 2009 to September 2010. It also shows the number of commencement of construction. Roughly, the industrial waste is produced a month behind the commencement. Fiscal year of house manufacturer M is from April to March. Therefore, the number of completion of construction increases in September and March.

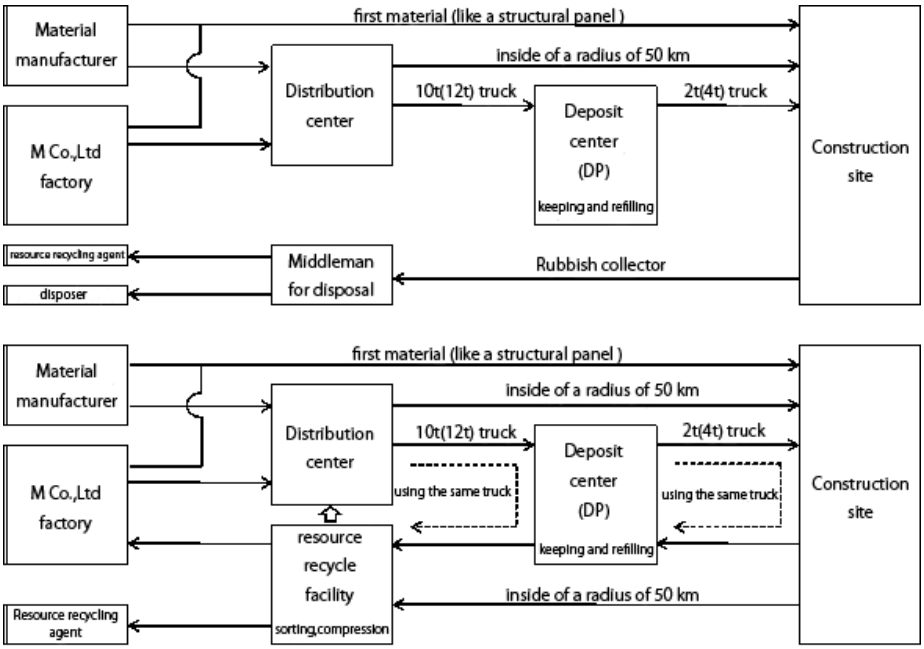


Figure 7: *Change of distribution by resource recycle facility*

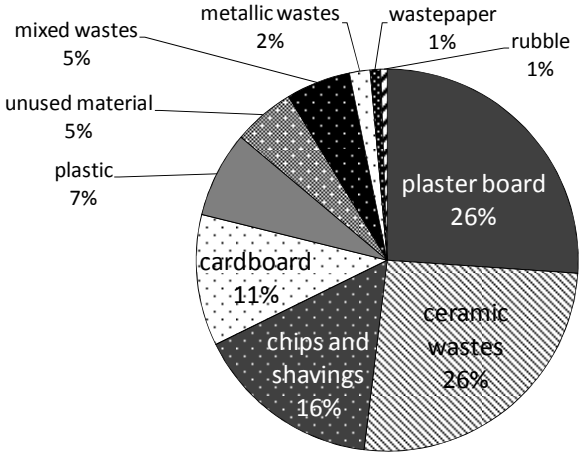


Figure 8: *Ratio of industrial waste from May 2009 to September 2010*

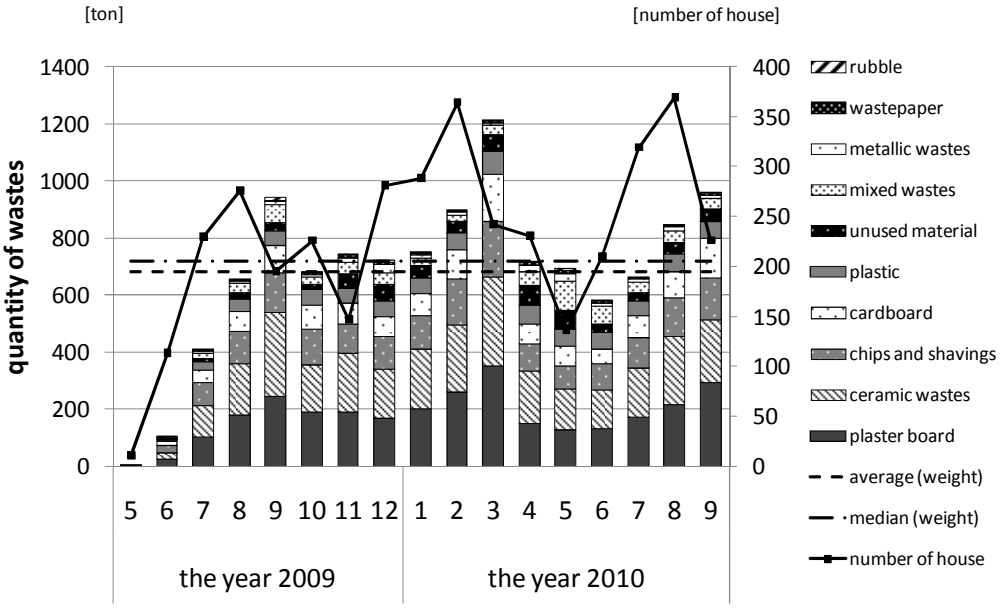


Figure 9: *Time series data of industrial waste brought from construction sites*

Figure 10 shows the industrial waste comparison among construction methods: the assembly of wood panels at site, the pre-assembly of wood panels with sash at factory, and the pre-assembly of wood panels with sash and siding at factory. The higher the ratio of prefabrication is, the less the quantity of industrial waste produced at construction site is. Of course, the quantity of industrial waste produced at factory shows countertrend.

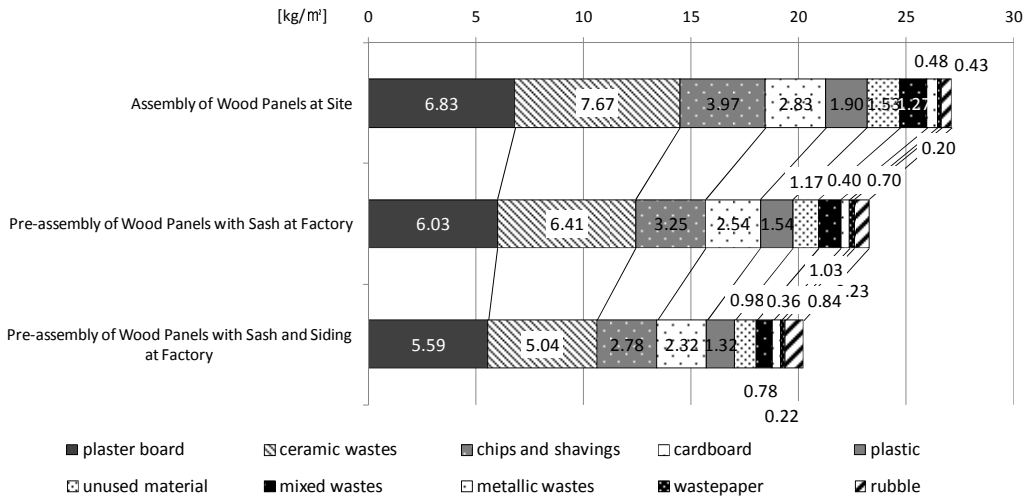


Figure 10: *Comparison of industrial waste brought from construction sites*

WASTE DISPOSAL OF PLASTER BOARD

Plaster board is the highest waste ratio in house manufacturer M. Table 3 shows the outline of construction projects for waste disposal survey. All of them adopt the pre-assembly of wood panels at factory. They are located at Tokyo and the neighboring prefecture in Japan. They are detached houses, and wood panel build 2-storied structure. The size of houses is similar.

Table 3: *Construction projects for waste disposal survey*

Project	S2	S3	S4
Location	Kashiwa City, Chiba, JAPAN	Yotsukaido City, Chiba, JAPAN	Hatogaya City, Saitama, JAPAN
Number of Stories	2	2	2
Site Area	150 ㎡	151 ㎡	152 ㎡
Total Floor Area	120 ㎡	127 ㎡	124 ㎡
Entresol Area	-	-	-
Construction Period	July, 2008 - September, 2008	December, 2009 - February, 2010	November, 2010 - December, 2010
Structure	Wood Panel Bonding Method		
Site Condition	Good for Construction		
Assembly of Wood Panels	Pre-assembly of Wood Panels with Siding at Factory		Pre-assembly of Wood Panels at Factory
Number of Delivery	3	3	3

Cutting of plaster board

The detail of cutting plaster board at construction site in projects is shown: S2 project in Figure 11 and S3 project in Figure 12. The number of cutting plaster board whose waste is the most in S2 project is 4. The average of quantity of waste is 3.15 kg. That in S3 project is 3. The average of quantity of waste is 2.18 kg. The manpower at construction site such as the cutting of plaster board is related to the adoption of precut. Less than 5 times cutting plaster board has a possibility of precut.

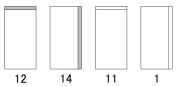
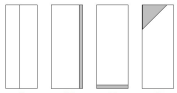
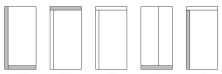
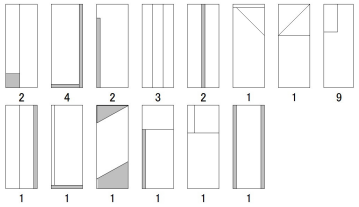
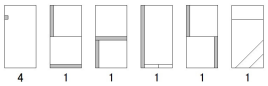
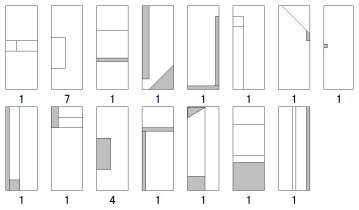
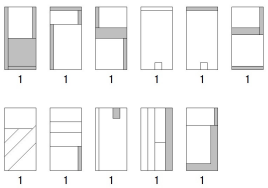
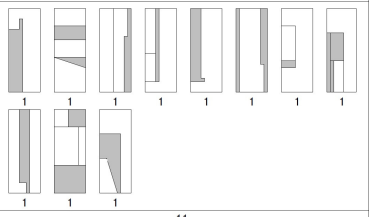
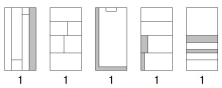
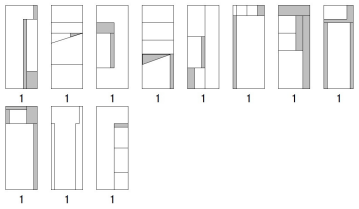
Cutting		3 syaku × 6 syaku	3 syaku × 8 syaku (1syaku = 0.3 m)
Once	Cutting form Number of board	 12 14 11 1	 9 15 2 1
	Total number of board	38	27
	Average of quantity of wastes (kg)	0.83	2.04
2 times	Cutting form Number of board	 9 2 6 1 1	 2 4 2 3 2 1 1 9 1 1 1 1 1 1
	Total number of board	19	30
	Average of quantity of wastes (kg)	1.20	2.93
3 times	Cutting form Number of board	 4 1 1 1 1 1	 1 7 1 1 1 1 1 1 1 1 4 1 1 1 1
	Total number of board	9	24
	Average of quantity of wastes (kg)	0.84	2.45
4 times	Cutting form Number of board	 1 1 1 1 1 1 1 1 1 1 1	 1 1 1 1 1 1 1 1 1 1 1 1
	Total number of board	11	11
	Average of quantity of wastes (kg)	2.65	3.65
5 times	Cutting form Number of board	 1 1 1 1 1	 1 1 1 1 1 1 1 1 1 1 1 1
	Total number of board	5	11
	Average of quantity of wastes (kg)	0.99	1.82
6 times	Total number of board	6	8
	Average of quantity of wastes (kg)	1.70	1.68
7 times	Total number of board	2	7
	Average of quantity of wastes (kg)	3.01	1.15
8 times	Total number of board	5	1
	Average of quantity of wastes (kg)	1.50	—
9 times	Total number of board	2	3
	Average of quantity of wastes (kg)	—	0.88
10 times	Total number of board	1	
	Average of quantity of wastes (kg)	—	
11 times	Total number of board	2	
	Average of quantity of wastes (kg)	0.45	
17 times	Total number of board	1	
	Average of quantity of wastes (kg)	—	

Figure 11: *Detail of cutting plaster board at construction site in S2 project*

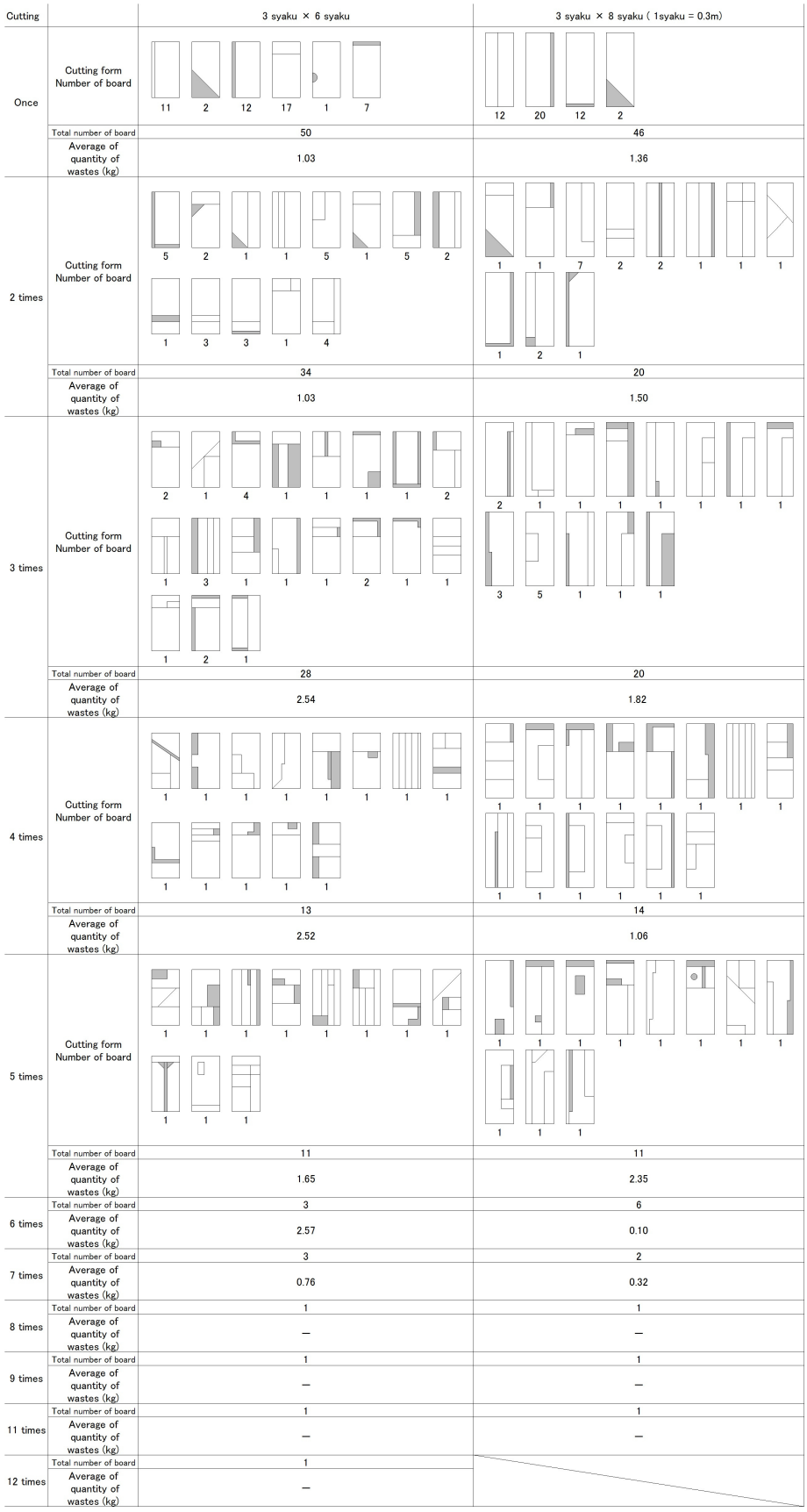


Figure 12: *Detail of cutting plaster board at construction site in S3 project*

Carry-in and carry-out plaster board

The survey weighs the plaster board in projects at the time of both the carry-in and the carry-out. Table 4 shows the result of carry-in and carry-out in S2 project. The weight of carry-in plaster board is converted with the number of sheets. That of carry-out plaster board is weighed directly with a spring scale. The number of carry-in is limited. That of carry-out is scattered. Actually they are stocked at the edge of construction site and carried out at weekly intervals.

Table 4: *Weight of Carry-in (left) and Carry-out (right) Plaster Board in S2 Project*

Month	Day	910mm × 1,820mm (Number of Sheets)	910mm × 2,420mm (Number of Sheets)
8	25	70	0
9	3	40	80
9	8	0	61
9	13	6	0
Total Number of Sheets		116	141
Weight per Sheet (kg)		13.4	17.8
Sub-total Weight (kg)		1,554.4	2,509.8
Total Weight (kg)		4,064.2	

Month	Day	Plaster Board (kg)	Number of Carpenters	Work Area
8	25	74.0	2	Lathing
9	5	18.0	1	1F Wall
9	8	152.0	1	1F Wall
9	9	38.0	1	2F Wall
9	10	123.5	2	1F and 2F Ceiling
9	11	48.0	1	2F Wall
9	12	95.2	2	1F and 2F Ceiling
9	13	51.2	1	2F Ceiling
9	14	13.2	1	1F and 2F Partition
Total Weight (kg)		634.1	12	

Trial calculation with Material Flow Cost Accounting

The cost of plaster board is cheep. The reduction of material cost doesn't become incentive motivation. Material Flow Cost Accounting (MFCA) is an environmental accounting method originally developed in Germany. In addition to the cost of materials, labor cost, and other processing cost are allocated under loss cost, and waste cost is calculated by the same means as production cost. Therefore, waste is called "negative product" in MFCA.

Figure 13 is a trial calculation of plaster board work in project S4 with MFCA. The ratio of negative product is 19.8 %. The cost is 76,630 yen. It is more than three times material cost.

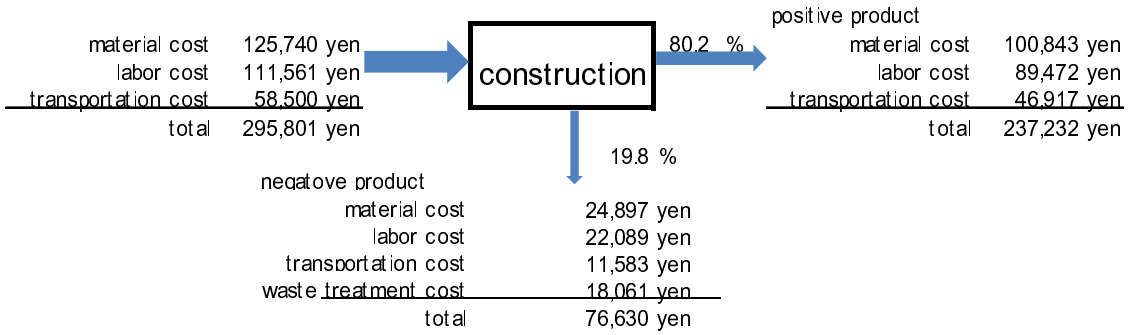


Figure 13: *Trial calculation of plaster board with MFCA*

CONCLUSIONS

The objective of this research is to analyze the function and effects of resource recycle facility in a Japanese industrialized detached house manufacturer.

First, the survey, based on questionnaire with 25 dealers beyond the scope of resource recycle facility, makes clear the actual condition of waste disposal. They are different. There is one dealer that separates 10 kinds of waste. There are three dealers that don't separate waste at construction sites. Over 70 percent of dealers adopt the separation of plaster board. Nearly half of dealers adopt the separation of chips and shavings, and cardboard. There are no systematic methodologies such as the waste disposal data analysis.

Secondly, this survey makes clear the before and after comparison of logistics with resource recycle facility. After the establishment of the facility, 10 ton trucks go around among the distribution center, the deposit center and the resource recycle center. 2 ton trucks go around among the deposit center and construction sites. Special common pallets for both the delivery of materials and the collection of industrial waste are used over and over again. This survey verifies that the material flow has been streamlined.

This survey analyzes the ratio of industrial waste collected to the resource recycle facility from May 2009 to September 2010. The ratio of plaster board and ceramic wastes is 26 % and is the highest. That of chips and shavings is 16 %. That of cardboard is 11 %. Moreover, the higher the ratio of prefabrication is, the less the quantity of industrial waste produced at construction site is. This analysis shows the difference of construction methods.

This survey also shows the time series data of quantity of industrial waste brought from construction sites from May 2009 to September 2010. Roughly, the industrial waste is produced a month behind the commencement. Fiscal year of house manufacturer M is from April to March. Therefore, the number of completion of construction increases in September and March. Moreover, the higher the ratio of prefabrication is, the less the quantity of industrial waste produced at construction site is. This time series data analysis of quantity of industrial waste shows the task of load leveling of resource recycle facility.

Thirdly, this survey makes clear of the site fabrication of plaster board. Four times and five times cutting plaster board produces more waste. The most of waste quantity is 3.65 kg. The manpower at construction site such as the cutting of plaster board is related to the adoption of prefabrication. Less than 5 times cutting plaster board has a possibility of precut. This survey also shows a trial calculation of plaster board work with MFCA (Material Flow Cost Accounting). The ratio of negative product is 19.8 %. The cost is 76,630 yen. It is more than three times material cost. This indicates the importance of rationalization of waste disposal. There is a room for improvement of waste disposal system.

Finally, this paper makes clear the before and after comparison of the establishment of the resource recycle facility by house manufacturer itself. This survey indicates that the load leveling of resource recycle facility and the adoption of construction methods such as prefabrication and precut are worthy of consideration from the standpoint of environment management. After this, the research will survey the detail of waster separation and disposal in the resource recycle facility.

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