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Lifetime distribution of buildings decided by economic situation at demolition: D-based lifetime distribution

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Abstract

By using the balance equation between input, output, and net addition to stock, we developed a method to estimate the lifetime distributions for buildings by statistics and some parameters from former studies. Understandable lifetime distributions were obtained from 1987 to 2010 in the type of lifetime distributions for cohort demolished in each year (D-based lifetime distribution), which was based on a hypothesis that demolition would be decided by some reasons at the time of demolition. We found that time-series change of the average lifetime depends on the economic situation, at least in the country where replacement is the dominant method of construction.

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Keywords: lifetime distribution functions; time-series analysis; a dynamic model; net addition to stock; demolition of buildings

1. Introduction

Buildings ultimately are demolished after a certain period of service. Understanding lifetime distributions of buildings are of importance for life cycle assessment (LCA), life cycle management, maintenance engineering, recycle and resource circulation, and sustainable consumption and production. A dynamic approach in material flow analysis (MFA) demonstrates the relationship between building construction, use, and demolition[1]. Similar approaches are cohort analysis, used in demography[2] and fleet or longitudinal analysis for automobiles[3, 4]. The dynamic approach can estimate a breakdown of in-use and demolished buildings by year of construction. This breakdown is useful for forecasting the generation of demolition waste and for evaluating changes of demands and demolition from longer lifetimes produced by new technology and/or legislations. In addition, building lifetimes are a key parameter for LCA and MFA in industrial ecology[5, 6]. In former LCA studies on buildings, building lifetime has been presumed despite the fact that energy consumption during use account for a large share of it in their whole lifecycles [6-8]. A lifetime of buildings also plays a key role in a dynamic MFA, especially in regards to steel[9], concrete, wood, and other materials related to buildings.

For many types of products, products in use and disused are not distinguished by their ages. In general, the actual lifetime of a group of products is not determined because it is time and cost consuming to investigate it[6, 10]. The exceptions are products which have a registration system; e.g. automobiles in Japan. The data on automobiles in Japan indicate a trend towards increasing product longevity[6, 11]. Hashimoto and Terashima [1] estimated demolished floor area in Japan by a dynamic approach using the actual distribution of building lifetimes as investigated in 1987[12] and pointed out that the estimated floor area was less than the floor area reported in official statistics[1]. They concluded that the lifetime of buildings in Japan might become shorter during the 1990's. Murakami et al. reported that the average lifetime of mobile phones became 1.5 times longer between the year 2000 and 2008[13]. Thus, in general product lifetimes can vary over time. A change of building lifetimes over time has not been analyzed so far.

Most studies on lifetime have regarded a product's lifetime distribution as the distribution of the product population produced or constructed in a certain time period. One reason

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for this is that, when designing products, expectations of service lifetime are important. Oguchi et al. [6] introduced another type of distribution, which is the population discarded in a certain time period. This concept is useful because in reality, replacement of products with more advanced models, moving and other changes of lifestyle may be factors deciding the choice to discard products. In this study, we presumed that lifetimes of buildings would be decided not by factors related to construction, such as design, but by factors in effect at the time of demolition, particularly those typical in developed countries; in Japan, new buildings are constructed mainly by replacing old ones. This study aims to understand the time-series change of building lifetimes by means of the lifetime distributions for buildings demolished annually in Japan.

Nomenclature

i	an index for construction types and usages as the subscript
t	the year observed
x	the year constructed
y	a lifespan of the product
D(t)	demolished floor area in the year ***t***
C(x)	constructed floor area in the year ***x***
S(t)	existing floor area at the beginning of the year ***t***
R(y,t)	a rate of the buildings remaining past ***y*** years after construction at the beginning of the year ***t***
w(x,t)	the portion of the floor area of buildings which constructed in the year ***x*** and demolished in the year ***t*** to the total constructed floor area in the year ***x***
$d_t(x)$	a percentage of annually demolished floor area constructed in the year x to total demolished floor area in the year t
r(x)	a partial differential function of the function D with respect to t -x

2. Method

2.1. Data availability and preparation

In Komatsu et al. [12] lifetime distributions of buildings, were distinguished by construction types, such as wooden, reinforced concrete (RC), steel construction, steel reinforced concrete (SRC), concrete block and others, and by usages, such as residential and non-residential. Although we used these same categories, due to availability of data on floor area of existing buildings, construction floor area, and observed building lifetime distribution we selected for analysis five building types: wooden residence, steel construction residence, steel construction non-residence, reinforced concrete residence, and reinforced concrete non-residence.

In Japan, statistics on buildings, floor area constructed annually and residential floor area constructed annually are prepared by structure type from the year 1951. Floor areas of non-wooden structures constructed in 1951 were significantly smaller than floor areas of structures constructed in recent years, which is not taken into account in this study. We estimated the past construction floor area of wooden residences constructed before 1950 by using the remaining number of buildings and the rates that buildings remain for the year 1987 as reported by Komatsu et al.[12]. In this estimation, we assumed the floor area per building is constant prior to 1951, and is the same size as in 1951.

Demolished floor area in Japan is compiled in official statistics. These statistics gathered the floor area demolished reported to public offices, however, it is known that some demolished buildings do not have their actual areas reported [1]. Consequently, values for demolished floor area were estimated by using existing floor area, construction floor area which have higher integrity, and by using equation 1.

$$D_i(t) = S_i(t) + C_i(t) - S_i(t+1) \quad (1)$$

Existing floor areas were obtained for the years 1983 to 2011 by construction type and usage. Using equation 1, demolished floor areas were calculated for 1983 to 2010.

2.2. Expressions of lifetime distribution

On one hand, demolished floor area was obtained from statistics as in equation 1. On the other hand, equation 2 is another way to express the demolished floor area by using constructed floor areas from previous years and building lifetimes, expressed in a form of rate of buildings remaining, which is the basic equation in this study. When the lifetime of buildings is given in a form of rate of buildings remaining demolished floor area during the period concerned is obtained for the sum of the products of the difference of the rate of remaining buildings at the beginning of the period concerned and the beginning of the next period and the constructed floor area in each corresponding constructed year. This paper covers a period of analysis selected due to data availability.

$$D_i(t) = \sum_{x \le t} C_i(x)\big(R_i(y,t) - R_i(y+1,t+1)\big) \quad (2)$$

The remaining rates in equation 2, which is expressed in the form of a cumulative distribution function along with lifetime of products, can be rewritten to the form of probability density function as shown in equation 3.

$$D_i(t) = \sum_{x \le t} C_i(x) w_i(x,t) \quad (3)$$

In Fig. 1, the construction year, ***x***, is the x-axis, the observation year, ***t***, is the y-axis, the demolished floor area, ***w(x,t)***, is the z-axis, resulting in the distribution shown. As described in Fig.1, two types of lifetime distributions can be defined: the construction year distribution (hereafter C-based) is drawn normal to the x-axis, and the discard year distribution (hereafter D-based) is drawn on the y-axis.

Variables in C-based distribution are valid for a cohort of buildings constructed in each specific year, which vary with factors at the time of construction, such as improving design for longer service life, changing regulations, increasing strength of materials, and so on. Here, the distribution ***w(x,t)*** is determined by the year of construction x, and is expressed in the form $\boldsymbol{w_x(t)}$ as a function of observation year. Variables in D-based distribution are valid for buildings demolished in