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Estimation of CO_2 emission of apartment buildings due to major construction materials in the Republic of Korea

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ABSTRACT

Buildings emit much greenhouse gases as large amounts of resources and energy are consumed during their life cycle. CO_2 emissions from residential buildings in the Republic of Korea ("Korea" hereinafter) are expected to consistently increase. According to the statistical data, apartment buildings occupy a high portion (86.4%) of residential buildings, and it is expected to maintain a certain level every year due to residential building construction policy of the Korean government. So, apartment buildings are a very important subject of study. This study aims to quantify CO_2 emissions emitted by six different size apartment units due to major construction materials consumed in construction. The result shows that CO_2 emission of the various construction materials of an apartment unit was estimated to be 569.5 kg-CO_2/m^2 on average. The apartment with the area of 84.9 m^2 for a common apartment type in Korea has about 11.8 TOE embodied energy and 45.1 ton-CO_2 emission. The CO_2 emissions from steel and concrete were 424.2–584.2 kg-CO_2/m^2 for apartment units, occupying more than 82% of the total CO_2 emissions. The results are valuable for the sustainable design of apartment complexes and are used as technical measures for the CO_2 reduction strategy of the building sector.

1. Introduction

In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) was adopted in Brazil to prevent the occurrence of abnormal climate phenomenon caused by the greenhouse effect. Later, many countries in the world would join to make their best efforts in reducing their respective greenhouse gas emissions by reducing their use of fossil fuels. Korea, as a forerunner among the developing countries, is planning to implement the Kyoto Protocol to reduce its CO_2 emissions and it is expected that it is necessary to perform its CO_2 reduction commitment during the second commitment period (2013–2017) [1]. As of 2006, the total amount of greenhouse gas emissions caused by the combustion of fossil fuels was about 600 million tons; therefore, making the country the 9th biggest source of CO_2 emission in the world [2].

The building sector should be prioritized in order to be able to reach a sustainable society because the building sector constitutes almost 30% of global CO_2 emissions [3]. CO_2 emission in the building sector comprises about 23% of total CO_2 emissions of Korea [4]. Numerous studies have shown that operational energy accounts for about 85–95% of the total energy use in dwellings during a service life of 50 years [5]. As environmental issues continue to become increasingly significant, the energy required for construction and for the material production is getting of greater importance. The building's total embodied energy is proportional to the amount of the material used in construction stage and to the value of the material's embodied energy [6]. Thus, we should consider the environment and mitigate the environmental impacts of building construction.

Although a number of studies have been conducted on energy consumption and CO_2 emission during life cycle of buildings, very few attempts [7–9] have been made at construction stage in particular. Suzuki et al. [7] used the input/output table of Japan to calculate the amount of embodied energy and CO_2 emission from various types of housing construction and recommended that construction of house required a huge amount of energy and accounted for a substantial portion of the nation's energy use. Gonzalez and Navarro [8] proposed that the designer make important decision to reduce CO_2 emission in design phase by selecting low environmental impact construction materials for the building construction stage. Yan et al. [9] published a study to establish a calculation method for CO_2 emission in building construction and to apply it to a practical case building. It is necessary to consider not only

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energy consumption and CO_2 emissions resulting from the operation and maintenance of buildings by energy efficiency, but also efficient use of construction materials and improvement of their CO_2 intensity in order to reduce greenhouse gas emissions from building construction.

Therefore, this study aims to quantify CO_2 emissions caused by six different size apartment units subject to major construction materials consumed in the new apartment construction. Because embodied energy and CO_2 emitted from the construction materials mainly involved in construction stage, we estimated their environmental impact (CO_2) caused by the construction of whole new apartment buildings in Korea every year. The results from this study will be used as basic data for the sustainable design of buildings and choosing construction material for apartment buildings.

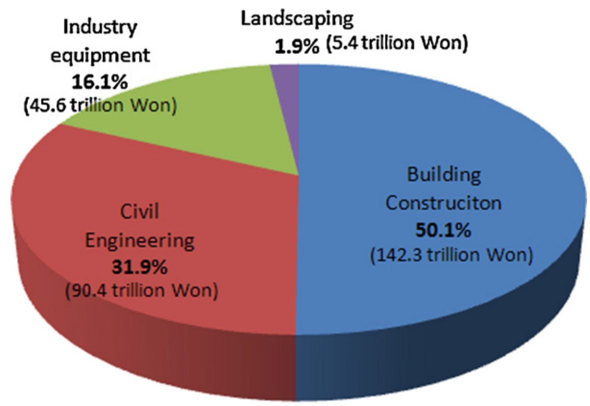

Fig. 1. Share of the construction industry in Korea in 2008.

2. Methodology

2.1. Apartment buildings in Korea

In this study, we investigated the size and composition of the building sector in Korea's construction industry and the weight of apartments among those. Through this, we estimated the importance of apartments as a preferred assessment subject among various construction sectors and the scale of new residential buildings annually built.

In every country, the construction industry is a major contributor to socio-economic development and also a major user of energy and natural resources. It is essential to involve the building construction industry to achieve sustainable development in the society [10]. The construction of buildings has an impact on many other industries because of the use of various kinds of materials, which are produced in various categories of industry [7]. According to data from the Worldwatch Institute, the construction of buildings consumes 40% of the stone, sand and gravel, 25% of the timber and 16% of the water used annually in the world [11]. According to the report by the Bank of Korea [12], the construction industry occupies 9.3% of GDP with its production amounting to 40 billion USD in Korea and building construction occupies about 50.1% of the entire construction industry. In this respect, it was significant that the estimation of embodied energy and CO_2 emission caused by the construction stage of buildings in Korea.

Fig. 1 shows the composition ratio of the entire construction industry in Korea in 2008 and this value is based on monetary value of orders received by kind of construction. Total monetary value of the construction industry in Korea was about 284 trillion won (nearly 237 billion USD) [13]. In the entire construction industry, building itself occupies about 50.1%, followed by civil engineering (31.9%), industry equipment (16.1%), generation plant facilities and landscaping.

According to Korean government agencies' construction statistics [14], the number of residences built in a year has been in the range of about 460,000–600,000 during the past five years, and as of 2008 there are about 13.2 million houses. Here, the numbers of residences are all buildings for residential purpose included detached houses, apartments and complex housing facilities. Korea Ministry of Construction and Transportation (MOCT) reported that 500,000 homes will be built annually despite the recent global economic recession [14,15]. So we see from Fig. 2 that the number of houses in Korea is expected to reach 19.22 million in 2020.

The component ratio of the amount of orders received in the building construction sector is shown in Fig. 3. Regarding the current status of the composition of the orders for building construction, the building for residences occupies about 45.4–48.6%; furthermore, among these orders, apartments occupy the highest ratio at 86.4% of residential buildings. The average floor area of units for residential purpose increased from 58.2 m^2 to 81.5 m^2 between 1975 and 2008, but is expected to maintain at present conditions as the number of people per household is gradually decreasing.

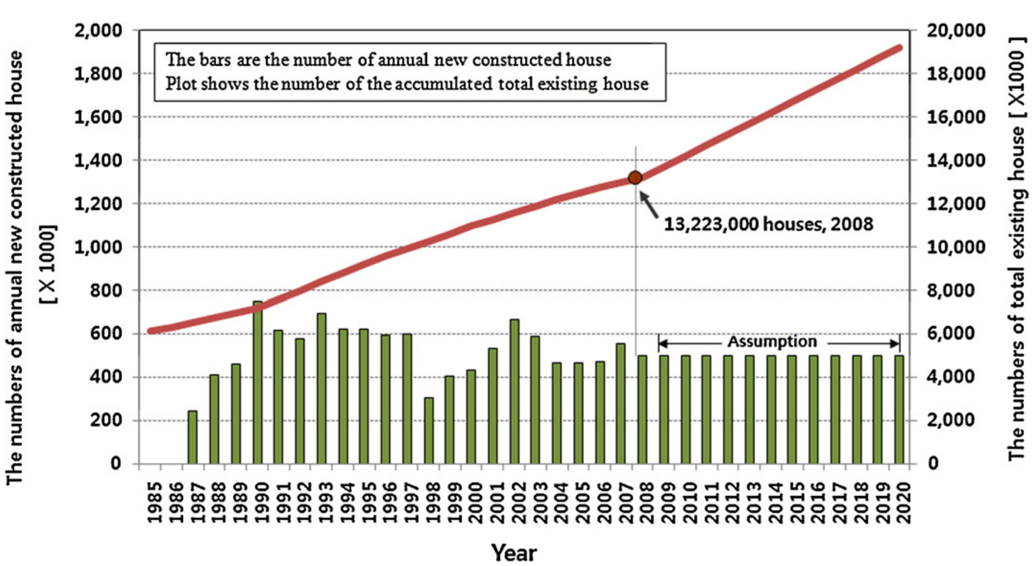

Fig. 2. Annual new constructed houses and total existing houses in Korea.

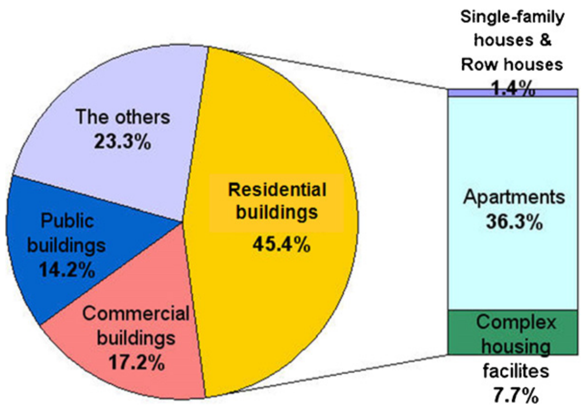

Fig. 3. The component ratio of the amount of orders received in the building sector.

Because new towns are under construction continuously as a part of a national land development program of the Korean government, there is little possibility that the construction of apartments will lessen; thus, the influence of such construction will have a continual impact on CO_2 emissions.

Energy consumption in the building sector grew from 16 million-TOE in 1980 to 35 million-TOE in 2000, and then recorded at about 40 million-TOE in 2008 [16]. The average annual growth rate between 1998 and 2006 was about 3.5%. The average energy consumption of residential buildings has a range 176–290 kWh/m^2/year in Korea.

The annual amount of energy consumption of residential building in Korea was found to be about 21 million-TOE as of 2008, and electricity and natural gas as energy source account for 70% of total energy consumption. The estimated share of residential energy consumption by end use is as follows: space heating 44.2%, hot water 23.8%, space cooling 2.0%, cooking 9.0%, lighting 1.7% and electric appliance 19.1% [16]. Regarding the energy cost by household, there is no large difference in terms of region, as the energy cost of detached houses was about 20% higher than those of general apartments regarding residential building type [17]. Such a difference is due to the fact that most detached houses use comparatively expensive oil fuels as their energy source, as opposed to natural gas or district heating energy.

2.2. Case study apartment units

The six apartment units were the most typical type of apartments in Korea. Their floor areas are 29.9 m^2 (case A), 46.2 m^2 (case B), 59.6 m^2 (case C), 84.9 m^2 (case D), 102.5 m^2 (case E), and 149.5 m^2 (case F). These floor areas do not include public areas as elevator halls, public entrance areas, corridors, staircases and parking areas. Fig. 4 shows the floor plan and the layout of the studied apartment units.

The materials for the construction of an apartment include building construction materials, machinery, engineering materials and landscape architecture materials, and the types of building construction materials are most largely input among those. There are 500–1500 kinds of construction materials of total construction works that are required in constructing one apartment building.

This study classified major construction materials into three categories: structure materials, finishing materials and equipment materials; thirteen different materials commonly found and used in abundance in the construction of the apartment buildings were addressed. These major construction materials based on total mass include: steel bar (reinforcing rod), ready-mix concrete, plywood mold, concrete pile, room carpet (laminated paper finishing), tile, cement, clear glasses, plaster board, copper pipes, plastic pipes, electric wires and lighting fixtures. Table 1 shows the total amount of major construction materials used in the construction of each case.

2.3. CO_2 emissions of major construction materials

The management of energy and material resources is a key topic in the development of a sustainable construction industry. The environmental sustainability of processes and products is increasingly evaluated by a life cycle assessment method and several studies [10,18–20] have been made on the environmental impact of buildings during their life cycle. Buildings emit CO_2 as they consume large amounts of resources and energy through building construction using various materials and during their life cycle. However, this study only includes CO_2 emission embodied from construction materials in the building construction stage. We are here concerned with typical apartments in Korea. This study quantified CO_2 emissions produced by the input of materials in the construction of new apartments in Korea and analyzed CO_2 emissions by each unit of apartments from the assessment result.

The consumed amount of major construction materials for the studied apartment units was quantified by reviewing published reports [21] by housing construction companies and direct observations. Embodied energy is the energy consumption including direct and indirect effects from production of construction materials and the value of it is the embodied energy intensity. The value of CO_2 emission units is the amount of CO_2 emitted from the production of construction materials. Former studies [22] had obtained the embodied energy and CO_2 emissions of construction materials by using energy input–output analysis. Several studies [7,19,22] have been made on embodied energy and CO_2 emissions by the energy input–output analysis method.

In this study, CO_2 emissions from manufacturing of major construction materials are important factors. The unit amounts of embodied energy and CO_2 emission utilized in this study have been summarized in the following Table 2. The energy input–output analysis was used to calculate the embodied energy and CO_2 emission of construction materials in this study. It can be seen that steel bar is the most significant material in terms of embodied energy and CO_2 emission, with levels of about 42.29 kWh/USD and 14.66 kg-CO_2/USD, respectively.

Cement is one of the most common materials for building and has CO_2 emission of 7.94 kg-CO_2/USD. Plaster board used in finish material has comparatively large CO_2 emissions, at approximately 4.04 kg-CO_2/USD.

3. CO_2 emission analysis results

Fig. 5 shows the results of the assessment for CO_2 emissions in each case. As a result, CO_2 emission of the studied apartment units was evaluated to be about 569.5 kg-CO_2/m^2 on average. The results show the embodied energy of construction materials of case A apartment unit, a wall-type structure apartment, was about 4.0 TOE, and CO_2 emission was assessed to be 15.2 ton-CO_2. In case of the one with the area of 46.2 m^2 (case B), the embodied energy was about 6.3 TOE, and CO_2 emission was evaluated to be 24.3 ton-CO_2. The embodied energy was about 10.7 TOE and CO_2 emission of case C was evaluated to be 41.1 ton-CO_2 that the CO_2 emission unit was found to be the largest, which is about 689.5 kg-CO_2/m^2. The embodied energy of case D was about 11.8 TOE and CO_2 emission was evaluated as 45.1 ton-CO_2. In case E, the embodied energy was about 16.1 TOE and CO_2 emission was evaluated to be 61.8 ton-CO_2. Finally, largest analysis case (case F) with an area of 149.5 m^2 had about 21.6 TOE the embodied energy and 83.3 ton-CO_2 emission.

Table 1
Amount of major construction materials required for each apartment unit.

Materials (unit)	Case A	Case B	Case C	Case D	Case E	Case F
Structure materials						
Concrete pile (ea)	2.1	3.1	5.4	4.6	5.7	7.4
Concrete (kg)	58,119.3	84,169.4	148,488.8	165,108.7	237,930.2	299,071.8
Steel bar (kg)	2510.8	4173.1	7102.6	7357.8	10,134.6	14,375.2
Plywood mold (kg)	1475.0	2536.1	3883.3	4453.0	6324.0	7567.7
Finishing materials						
Cement (kg)	1232.6	1801.3	3005.9	4271.7	4511.2	5643.1
Tile (m^2)	28.4	32.1	51.4	63.9	73.8	94.9
Clear glass (m^2)	10.3	13.7	25.7	33.6	40.5	63.5
Plaster board (sheet)	30.1	46.8	70.7	94.7	118.8	158.3
Carpet (m^2)	23.8	46.9	68.8	45.4	35.9	49.5
Equipment materials						
Copper pipe (kg)	5.0	11.6	47.9	57.2	118.2	135.8
Plastic pipe (m)	37.8	126.6	252.1	372.9	526.0	633.8
Electric wire (m)	142.1	426.3	332.9	1203.7	1352.8	1550.5
Lighting fixture (set)	2.9	8.7	7.0	25.6	28.1	32.8

It was said that CO_2 emission per unit floor area was analyzed as about 557.1 kg-CO_2/m^2.

It can be showed from Fig. 5 that steel bar as a construction material has higher values of CO_2 emissions as compared to other materials. In all cases, steel bar occupied about 57% of total emissions. The CO_2 emissions from steel bar and concrete were 424.2–584.2 kg-CO_2/m^2 for apartment units, occupying more than 82% of total CO_2 emissions. Cement, one of the most general

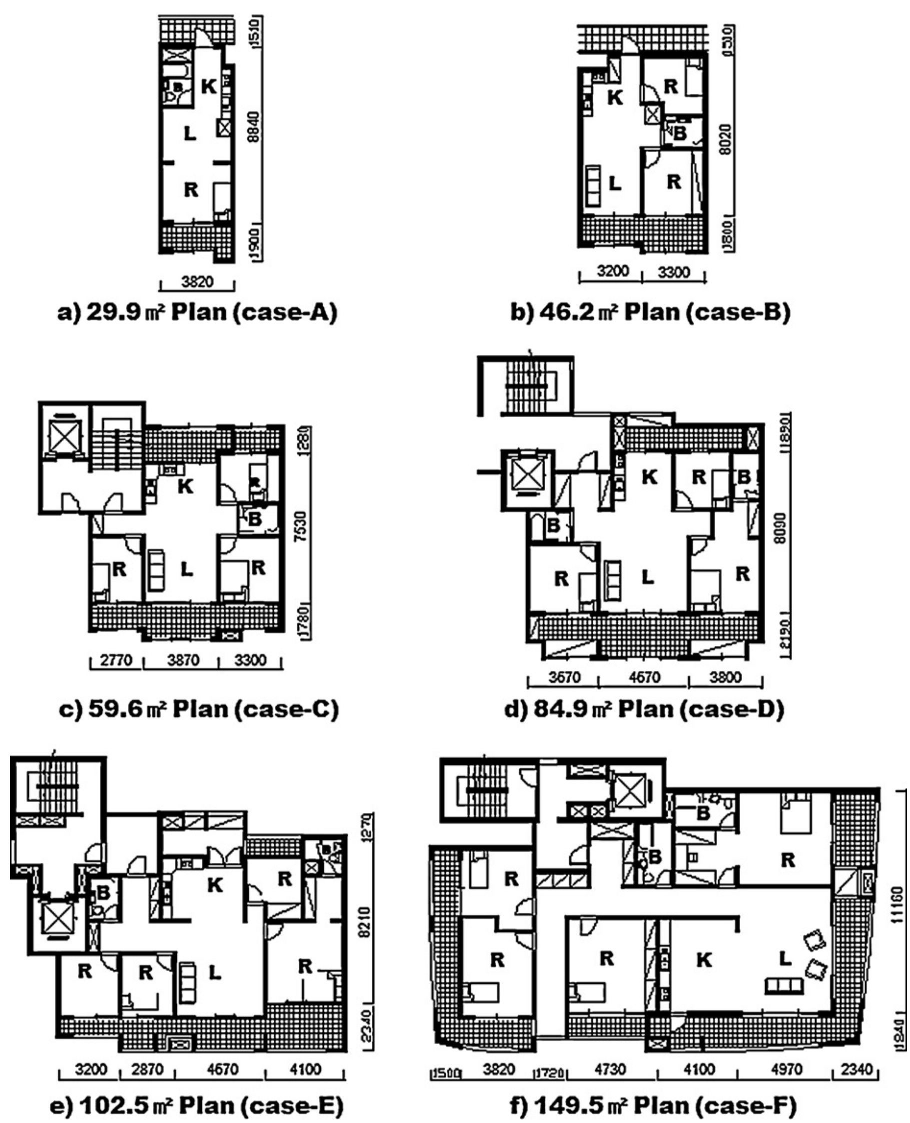

Fig. 4. Floor plans of the six apartment units.

Table 2
The embodied energy and CO_2 intensities of major construction materials.

Materials	Unit price (USD $)	Unit	Embodied energy		CO_2 emission	
			(kWh/unit)	(kWh/USD)	(kg-CO_2/unit)	(kg- CO_2/USD)
Concrete pile	0.06	ea	0.73	12.10	0.23	3.84
Concrete	0.02	kg	0.21	11.97	0.07	3.78
Steel bar	0.24	kg	10.11	42.29	3.51	14.66
Plywood mold	0.66	kg	2.02	3.07	0.61	0.92
Cement	0.04	kg	1.00	24.40	0.32	7.94
Tile	6.00	m^2	65.82	10.97	18.33	3.06
Clear glass	3.67	m^2	40.27	10.98	11.51	3.14
Plaster board	2.81	Sheet	37.33	13.27	11.35	4.04
Carpet	3.58	m^2	18.15	5.07	5.60	1.56
Copper pipe	3.18	kg	9.98	3.14	3.02	0.95
Plastic pipe	0.24	m	1.31	5.43	0.40	1.67
Electric wire	0.06	m	0.22	3.46	0.07	1.06
Lighting fixture	25.83	Set	119.34	4.62	35.65	1.38

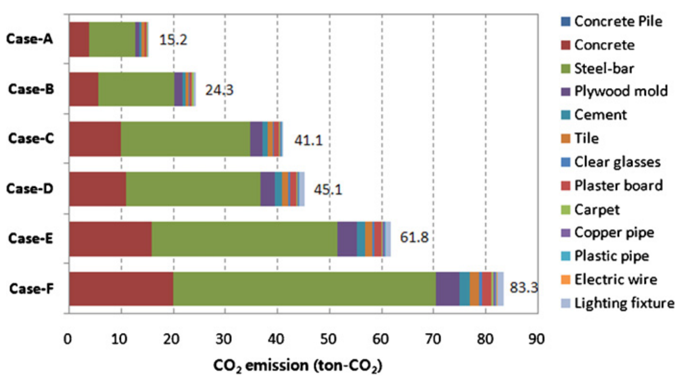

Fig. 5. CO_2 emissions by construction materials of apartment units.

construction materials, was 14.2 kg-CO_2/m^2 and occupied about 2.4% of total CO_2 emissions. The materials (copper pipes, plastic pipes, electric wires and light fixtures) used in equipment work account for 2.0% of total CO_2 emissions.

4. Conclusion

The major 13 construction materials consumed in the construction stage of new apartment units were analyzed and the amount of CO_2 emissions of six cases of apartment unit was calculated by using these major materials. The results permit the designer or the contractor to evaluate the environmental impact (energy and CO_2) of the construction material alternatives, during the design process.

It was found from the results that CO_2 emission of apartment units was about 569.5 kg-CO_2/m^2. The embodied energy of case D with the area of 84.9 m^2 for a common apartment type in Korea was about 11.8 TOE and CO_2 emission was estimated at 45.1 ton-CO_2. Steel, concrete and cement as construction materials are used in a very large quantity during building construction and they are the most significant in terms of environmental impact. The results indicate that steel, concrete and cement are responsible for 85% of the total CO_2 emissions resulting from residential apartment construction.

From the study results, we can suggest the following technical data to make a policy decision affecting the residential building construction market. Every year, the permitted number of new homes constructed in Korea is about 300,000 houses according to the annual statistical report by the Korean government [14]. Therefore, if the annual permitted number of new houses constructed domestically is assumed to be 300,000 houses and their average floor area is assumed to be 85 m^2, the carbon dioxide emitted from the construction of new apartments can be simply calculated as follows:

CO_2 emissions caused by materials involved for the construction of new apartments = the area of the newly constructed homes for residence (m^2) × ratio of apartments among the newly constructed homes × CO_2 emission per unit area (ton - CO_2/m^2) = (300, 000 homes × 85 m^2) × 86.4% × 0.5695 ton - CO_2/m^2 = 12.5 mega ton - CO_2.

If annually 500,000 homes will be built, we will foresee that CO_2 emission from the construction of new apartments will be about 20.9 mega ton-CO_2 annually.

Construction of buildings requires a huge amount of resources, and accounts for a substantial portion of the nation's industry. However, because the use of energy during life cycle of the building occupy a large portion, it is necessary to evaluate CO_2 emissions resulting from the operation and maintenance of apartments.

For reducing CO_2 emission, and its various potential effects on the earth, various building technology and construction materials have been developed and applied into fieldwork. For these reasons, it is important to secure substantial data on CO_2 emissions in the building sector in order to efficiently respond to the demands of the UNFCCC. Through this effort, greenhouse gas reduction plans in the building sector should be established and performed.

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