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Life cycle assessment in the environmental impact evaluation of urban development—a case study of land readjustment project, Hyogo District, Japan

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Abstract: In this paper, the Life Cycle of Urban Development was firstly analyzed, and the phases of Life Cycle Assessment applied to Urban Development (ULCA) were described. As a case study, ULCA was applied in the environmental impact assessment of the land readjustment project of Hyogo District of Saga, Japan. In addition, mitigation proposals for reducing CO_2 were also presented and the relevant environmental effects were simulated.

Key words: Life Cycle Assessment (LCA), Urban development, Environmental impact
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BACKGROUND

Life Cycle Assessment (LCA) includes an attempt to evaluate the environmental aspects of a product or a service in cradle-to-grave fashion. The first study on LCA was performed by the U.S. Midwest Research Institute for Coca-Cola Company in 1969 (U.S. Environmental Protection Agency, 1995). Till now, LCA has been applied in many fields, but mainly aims at product aspects in industry, such as product development, product improvement, and product comparison (U.S. Environmental Protection Agency, 1993).

On the other hand, with the speedy development of urbanization, the harmonization between development and environmental preservation has become one of the most critical targets. The environmental impacts of urban development could be severer than most of manufactured product both in quantity and quality. For example, in Japan, the CO_2 emission due to urban and architectural construction rose up to 50% of the overall emission in 1999 (Imura, 2001). Therefore, researches on the reduction of the environmental impact of urban construction are becoming more and more important. Many researches on environmental impact assessment of urban development had been conducted.

LCA is based on the very logical concept that if we can identify a system with a beginning and an end, we can investigate what it does to the environment from beginning to end, and can theoretically carry out LCA, so that we can make reasonable environmental decisions about that product or service. On the basis of such consideration, the application of LCA to urban development project will be a feasible and effective way for the environmental impact assessment. This kind of research, however, is not enough by far (Imura, 2001).

In this paper, we firstly analyze the Life Cycle of Urban Development Project comparing it with the general product LCA analysis and describe the implementation steps of LCA in Urban Development, which is called ULCA here. Then, we apply the ULCA to the land readjustment project of Hyogo District of Japan as a case study, as well as present the mitigation plan to reduce the environmental impact, and compare the pollution emission before and after the mitigation by simulation.

LCA IN URBAN DEVELOPMENT（ULAC）

1. Life Cycle of Urban Development Project

Life Cycle Assessment is called as a "cradle-to-grave" approach for assessing product manufacture. In the field of urban development, system boundary can also be set as shown in Fig.1, where PLCA stands for LCA of Product and ULCA stands for LCA of Urban Development Project. The most significant difference between the life cycle of general products and urban development project is that the period of life cycle duration of urban projects is much longer, the energy and materials input are much more, and sometimes large-scale readjustments of the project may be implemented. Considering such factors, the environmental impacts, especially the CO_2 emission are sequentially separated into the following different life cycle sections:

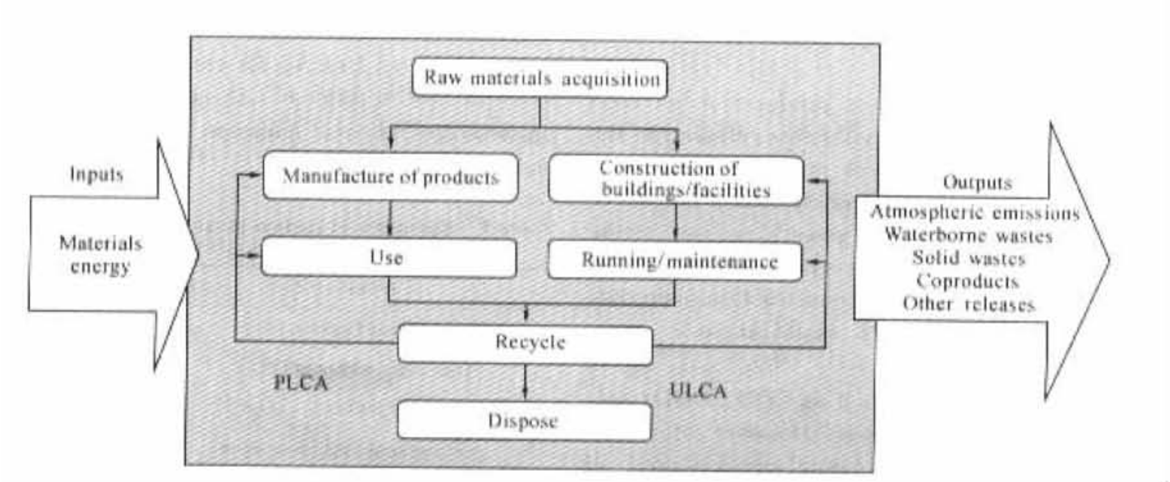

Fig.1 Life cycle of products and urban developments

（a）Construction material manufacture: such as that of the steel, iron and cement produced in factories;

（b）Construction: including the energy consumption and pollution disposal during the onsite construction;

（c）Running: such as energy consumption and waste disposal with the heating and cooling of buildings;

（d）Maintenance: implementation of the system's parts, management and adjustment;

（e）Disposal: includes the disposal of the buildings of infrastructures and waste management.

2. Benefits of conducting an ULCA

An ULCA will help decision-makers select the development plan or process that results in the least environmentalal impact, i.e. ULCA can help in finding the effective method of reducing the input such as materials and energy used in the life cycle of the project, as well as reducing the output such as atmospheric emission, waterborne waste, solid waste, and other wastes poluting the earth's environment. On the other hand, ULCA can also be used as one of the effective methods for environmental impact assessment（EIA）of the development.

3. ULCA process

ULCA is a systematic and phased approach that can be divided into four components as illustrated in Fig.2.

（a）Goal Definition and Scope is the first step of ULCA that describes the project, defines the purpose and method of applying ULAC, as well as establishes the context in which the assessment is to be made and identify the boundaries and environmental effects to be reviewed for the assessment. Although ideally a ULCA includes all stages of a project's life cycle, whether one or all of these stages should be included in the practical ULCA may be determined by considering the goal of the study, the required accuracy of the results, and the available time and resources.

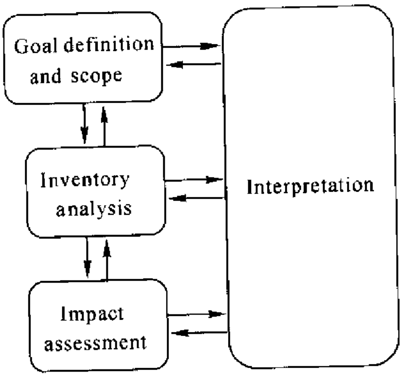

Fig.2 Phases of ULCA

(b) Inventory Analysis produces a list containing the quantities of pollutants released to the environment by the project throughout its entire life cycle (or during the period set by the above Goal Definition and Scope phase), as well as the amount of energy and material consumed. The inputs might include the construction materials and energy, the outputs would include atmosphere emissions such as CO_2, NO_2, CH_4 and so on; waterborne wastes such as COD, BOD; solid wastes and other releases. However, the evaluation indexes of environmental impacts used till now are mainly on the energy consumption during the life cycle, and the CO_2 emission accompanying the energy consumption.

In order to calculate the CO_2 emission value, many researches have been conducted, and some data have been published and are available during the calculation. The typical one is the "Energy Consumption and Carbon Dioxide Emission Intensities Based on Input-Output Analysis" (Yuichi, 1997), in which the CO_2 emission quantity (t-C, ton of Carbon Dioxide Equivalent) per million Japanese Yuan spent in different products or services are presented, which is called Carbon Dioxide Emission Intensities, with the unit of t-C/million Yuan. Here, the unit of t-C only takes the quantity of C in CO_2 into account, without considering the quantity of O in CO_2. The database includes 407 fields such as industry, agriculture, manufacture, and construction. Some of the Carbon Dioxide Emission Intensities related to construction are listed in Table 1. For example, Carbon Dioxide Emission Intensity for wood dwelling construction is 0.577116 t-C/million Japanese Yuan, which means that if one million Yuan is spent in the construction of wood dwellings, about 0.577116 t-C CO_2 is emitted directly and indirectly.

(c) Impact Assessment is the step to assess the human and ecological effects of energy and material consumption, and the environmental releases identified in the inventory analysis. This phase attempts to establish a linkage between the project and its potential environmental impacts. For example one of the typical impacts caused by emission from development projects is global warming caused be greenhouse gas emissions of CO_2, NO_2, CH_4, CFCs, HCFCs and CH_3Br. In this phase of ULCA, all greenhouse gases can be expressed in terms of CO_2 equivalents by multiplying the relevant emission results by a CO_2 conversion factor.

Table 1 Examples of carbon dioxide emission intensities related to construction (Yuichi, 1997)

Items	CO_2(t-C/million Yen)
Dwelling (wood)	0.57116
Dwelling (non-wood)	0.83525
Non-dwelling building (wood)	0.61190
Non-dwelling building (non-wood)	0.82337
Urban gas system	0.44023
Water supply system	0.93868
Sewerage system	1.09876
Road	1.12316
Heat supply	2.84521

(d) Interpretation is a systematic technique to identify, quantify, and evaluate information from the results of the inventory analysis and impact assessment, and relate them effectively to select the preferred plan, or to present the alternatives, which can reduce the environmental load. This stage aims to analyze results, reach conclusions, explain limitations and provide recommendations based on the findings of the preceding phases of ULCA.

A CASE STUDY OF ULCA IN THE LAND READJUSTMENT PROJECT OF HYOGO DISTRICT, JAPAN

1. Goal Definition and Scope

Hyogo District is located in the eastern part of Saga City and used to be farmland, which remained undeveloped until the Land Readjustment Project implemented in 1988. The purpose of this project was to control flood caused by the creek network running through the whole district, and develop new housings. The project covered 4100 residents and 66.7 ha, and cost 11.2 billion Japanese Yuan, including not only the construction of arterial roads, waterways and parks, but also the introduction of new public facilities. The basic project was started during 1984 to 1985; then the Hyogo Land Readjustment Association implemented the project from 1988 to 1999 (Municipal Office of Saga, 1999).

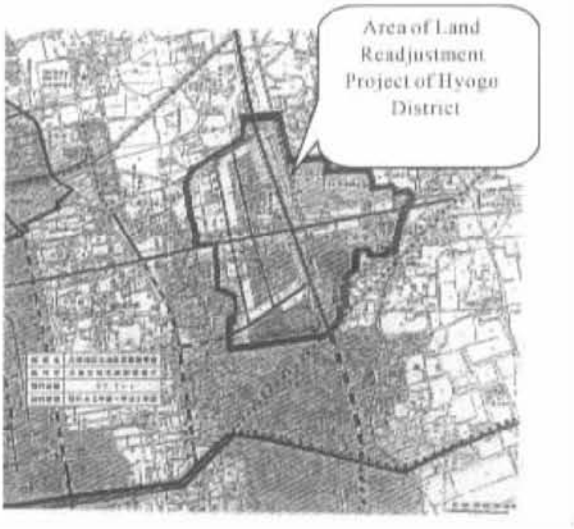

Fig.3 Land readjustment project of Hyogo District

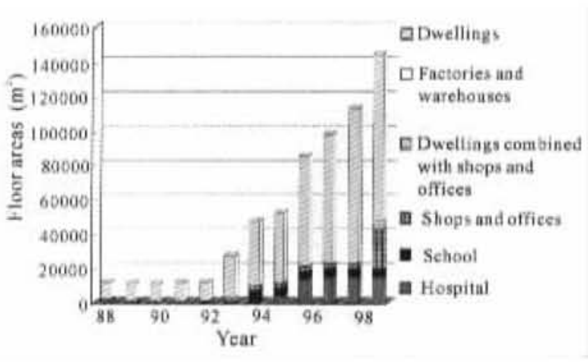

Fig.4 Land use of the project

In order to grasp the environment impacts of this project, we selected CO_2 emission as the evaluation index, one of the main indexes of environment load. Considering the goal of the study, the required accuracy of the results, and the available data resources, we set the ULCA boundary in the range from construction, maintenance to running. The raw material acquisition and manufacture, as well as the recycle and disposal stages are not taken into consideration, and these remaining stages will be calculated as the next step when we can collect enough data. The calculations are divided into two parts: public facilities and buildings. Public facilities consist of the land arrangement, provision of gas system, electricity, water supply system, sewerage system, road, park and green area, while buildings include dwelling houses, factories and warehouses, dwellings combined with shop and office, shops and offices, schools, hospitals.

2. Inventory analysis

During this research, we firstly obtained the rudimentary data of Hyogo District from Saga City Rudimentary Survey, including the data of construction cost, maintenance cost, utilization cost, and so on. We also conducted site surveys for the deficient data. As the second step, we calculated the environment load of the development in terms of CO_2 emission, which was divided into three parts: construction process, maintenance process and running process. By means of calculating the respective costs during the above three process and applying the CO_2 emission intensity based on input-output analysis (Yuichi, 1997), the CO_2 emission during the three processes can be obtained. The CO_2 emission intensities include the input and output of machine usage, manufacture and transportation of the materials, and electric power supply. The flow chart of this calculation is shown in Fig.5.

3. Impact assessment and interpretation

(1) Calculation methods

Eq.(1) below was used to calculate CO_2 emission:

$$E = \sum_{t=t_0}^{t_0+Y}(EC_t + EM_t + ER_t) = EC + EM + ER \qquad (1)$$

where: E – overall CO_2 emission during the service life (t-C);

EC_t – construction CO_2 emission in the year of t (t-C);

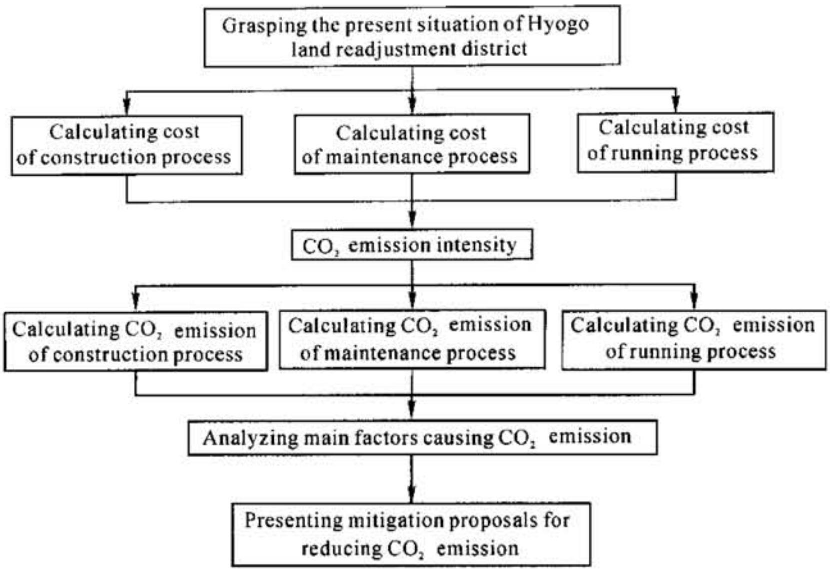

Fig. 5 Flow chart of the research

EM_t – maintenance CO_2 emission in the year of t (t-C);

ER_t – running CO_2 emission in the year of t (t-C);

EC – overall Construction CO_2 emission during the service life (t-C);

EM – overall Maintenance CO_2 emission during the service life (t-C);

ER – overall Running CO_2 emission during the service life (t-C);

t_0 – start year of service life;

Y – years of service life

and,

$$EC = \sum C_c e_c, \quad EM = \sum C_m e_m, \quad ER = \sum C_r e_r \tag{2}$$

where: C_c, C_m, C_r – cost of construction, maintenance and running of each item (million Yuan);

e_c, e_m, e_r – CO_2 emission intensity during construction, maintenance and running process of each of the items (t-C/million Yuan).

(2) Calculation results

As mentioned above, the calculations are divided into two parts: public facility and buildings, with both of them investigated within the scopes of construction, maintenance and running.

Public Facilities: The overall CO_2 emission quantity during construction process is 8465.6 t-C, in which that of road is 3608.8 t-C, being the largest proportion (43.5%); followed by emission from the sewerage system, being 2661.5 t-C (31.4%). The emission of CO_2 from public facilities during the maintenance process was extremely low, and was neglegible compared with the overall emission. The emission of CO_2 from public facilities during the running process increased rapidly from 1988 to 1999, especially the section due to road. The overall CO_2 emission from public facilities within the three stages of construction, maintenance and running during the period from 1988 to 1999 are shown in Fig. 6. The total CO_2 emission from public facilities during this period was 28288.2 t-c, in which the part of running (69.8%) ranked the first, then came construction (29.9%), and the third was maintenance

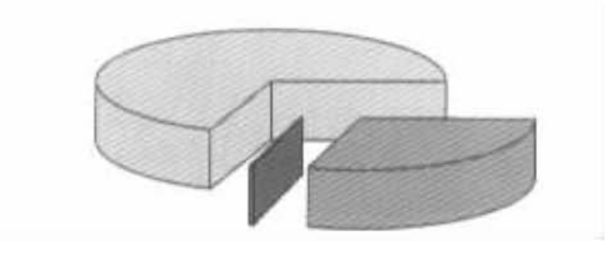

Fig. 6 Overall CO_2 emission from public facilities (1988 – 1999)

(0.3%).

Buildings: From 1988 to 1999 the CO_2 emission from buildings during the construction process was 7875.4 t-C, in which the CO_2 emission from dwelling's was 4599.9 t-C, which was the largest part (58.4%), followed by the emission from the construction of shops and offices, which was 1587.3 t-C (20.2%). The emission of CO_2 from buildings during maintenance increased sharply from 1992 to 1999, but was relatively low compared with that of the other two processes. The emission of CO_2 from public facilities during the running process also rose rapidly. As shown in Fig.7, the overall CO_2 emission from buildings from 1988 to 1999 was 23325.4 t-C, in which the emission of the running accounted for the largest proportion (53.0%), followed by that of construction procees (33.8%); then maintenance (13.3%).

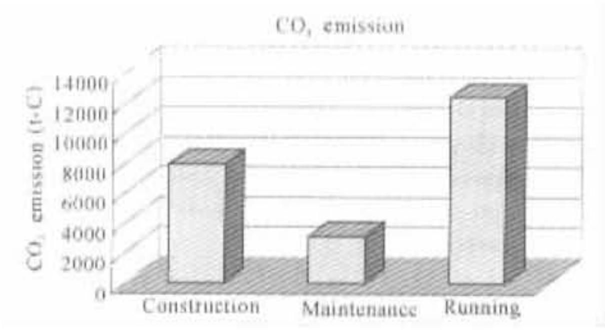

Fig.7 **Overall CO_2 emission from buildings (1988 – 1999)**

Comparison: The temporal changes of CO_2 emission from public facilities and buildings are shown in Fig.8, from which we can note that the CO_2 emissions accelerated from 1988 to 1999, both for facilities and buildings. From Fig.9, it is clear that both in facilities and buildings, the CO_2 emission percentage from the running stage is the highest among the three stages, while that from construction stage ranked the second, and that from maintenance stage was the lowest. The total quantity of CO_2 emission from the facilities was larger than that from buildings.

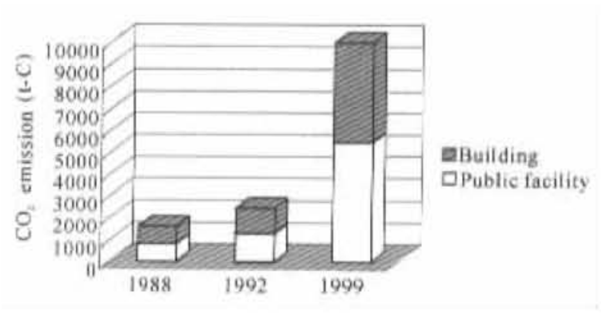

Fig.8 **CO_2 emission in 1988, 1992 and 1999**

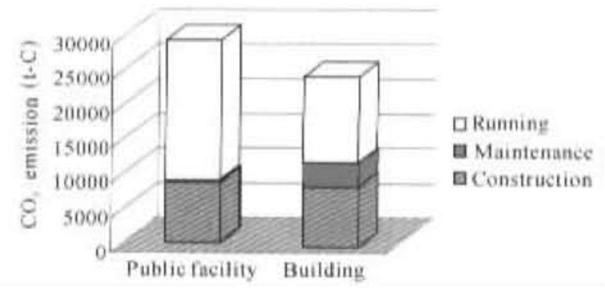

Fig.9 **CO_2 emission from facilities and buildings**

MITIGATION PROPOSALS AND SIMULATIONS

We presented some mitigation proposals to decrease the environmental impact of the development in Hyogo District, and then simulations of the effects of these proposals were conducted to check the effect of reducing CO_2 emission.

(1) Limiting land use of suburban commercial facilities: At present the areas of suburban commercial facilities such as dwelling combined with shop and offices, shops, offices and so on account for 17.5% of the total area of Hyogo District. According to our proposal, the area will be reduced by 5%, and then the reduced areas are supposed to be changed into dwellings. Thus, the CO_2 emission quantities will be reduced as shown in Fig.10; the running emission will especially be decreased to a considerable extent.

(2) Changing non-wood dwellings to low-stored wood dwellings: In our simulation, we changed the non-wood structure into low-store wood structure with the same architecture area, and the calculation results are shown in Fig.11. It can be seen that the CO_2 emission changed to 4599.9 t-C, dropping 23.9% than before.

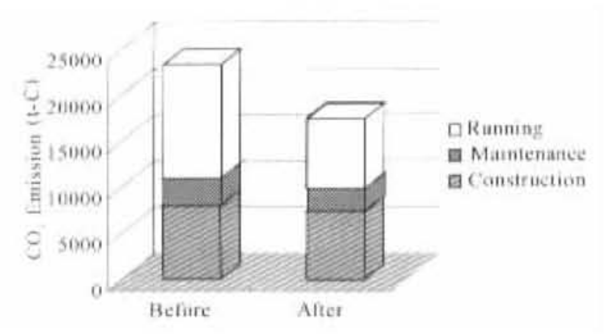

Fig.10 Chage of CO_2 emission by limiting land use of suburban commerical facilities

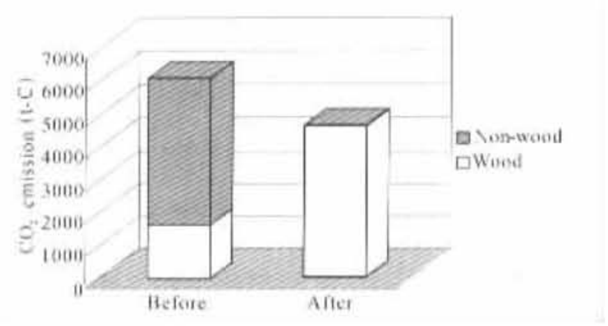

Fig. 11 Chage of CO_2 emission by changing non-wood dwellings to low-wood proportion dwellings

(3) Increasing the open space areas such as parks and green areas: At present, 4 local parks and 2 neighborhood parks have been developed and the overall area is 33000 m^2. The actual green areas in these parks, however, are very few by now. According to our proposal, camphor trees, the city tree of Saga City, are suggested to be planted in these parks. Trees are assumed to have been planted in the first year (1988) of the readjustment of Hyogo District. The calculation results are plotted in Fig. 12. According to our proposal, the overall number of trees planted in these open spaces is 516, and the absorption of CO_2 by these trees being 11138 t-C during the 12 years. Therefore 21.6% of the CO_2 emission in Hyogo District will be reduced.

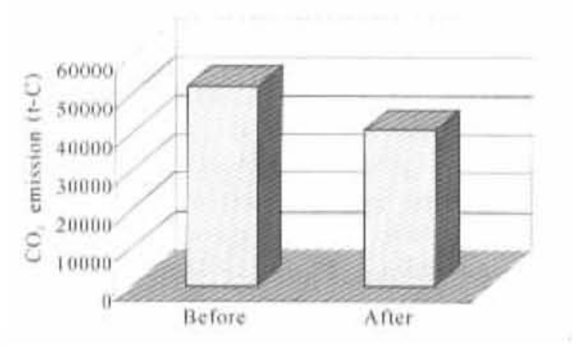

Fig.12 Chang of CO_2 emission by increasing green areas

CONCLUSIONS

In this research, the Life Cycle Assessment of Urban Development (ULCA) was analyzed and the implementation method was also presented. In the case-study of the Land Readjustment Project of Hyogo District, Japan, through the calculation of CO_2 emission from the phases of construction, maintenance and running of public facilities and buildings, the environmental impact by the urban development was analyzed. Furthermore, the mitigation proposals of environmental impacts were presented and their effects were simulated. It can be seen that ULCA is a feasible and effective way for environmental impact evaluation of urban development projects. As for future research, we will focus not only on the construction, running and maintenance stages of public facilities and dwellings, but also on the disposal, discharge and recycle stages, which can make this method more accurate and comprehensive.

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