EARTHQUAKE LOSS ESTIMATION FOR BUILDINGS IN ULAANBAATAR, MONGOLIA, BASED ON CONSTRUCTION COST INVENTORY DATA

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Abstract

Rapid urbanization movement has increased the concentration of population three times and buildings several times during the last two decades in Ulaanbaatar city (UB), Mongolia. The earthquake risk in this area has significantly increased due to uncontrolled development, poor construction practices without earthquake safety provisions, and lack of awareness amongst the general public and government authorities. On the other hand, there are several active faults, such as Hustai, Gunj, and Emeelt faults around UB. Especially, the Emeelt fault earthquake with the estimated maximum magnitude of 7 has been expected to produce a great impact on the UB region because the fault is located at only 20 km far from the city. To consider the disaster mitigation planning for such large earthquakes, the assessments of ground shaking intensities, and building damage for scenario earthquakes are crucial.

In order to assess the strong ground shaking and building damage, not only the distribution of site effects but also building inventory data is indispensable. The authors already assessed the site effects in the UB area by microtremor H/V spectral ratio (Tumurbaatar et al. 2019). In this study, we develop the building inventory data in UB, including construction year, structural types, construction cost, and construction levels for assessing the vulnerability of the buildings due to scenario earthquakes. Since the construction year and structural types are unknown for more than 50 % of the buildings in the existing inventory data, they crucial from building use, building area, number of stories, and urban land use. The construction costs for each building are evaluated based on the procedure of the Mongolian construction code. The costs are estimated from the coefficients of cost per floor area for each structural type, coefficients for heating system, floor areas, and locations of the buildings. The developed construction inventory would be used for assessing vulnerability (repair cost in percentage) of the buildings' strong shaking in future earthquakes. Finally, the construction levels for each building are estimated from construction year, building area, building use, and urban land use in order to assign vulnerability functions in GAR15 (Maqsood et al. 2013).

Keywords: building inventory, vulnerability function, damage estimation, economic loss, earthquake scenario, Ulaanbaatar

1. Introduction

Population growth, urban expansion, and increase of building density of Ulaanbaatar city (UB), Mongolia becomes vulnerable for earthquake hazards. Building damage estimation due to earthquake scenarios has been recognized as fundamental information for establishing earthquake disaster mitigation planning. In estimating earthquake damage, damage distribution of buildings is estimated by multiplying building inventory data by damage probability obtained from the seismic capacity of buildings and earthquake ground motion. Therefore, not only ground conditions such as site effects but also building inventory data are required for assessing the vulnerability of earthquake damage.

The site effects in the UB area were evaluated by the microtremor H/V spectral ratio [1]. Strong ground shakings due to a scenario earthquake can be estimated by strong motion prediction methods and the site effects. On the other hand, vulnerability functions for all the considerable building types have been proposed for assessing earthquake risk including vulnerability (repair cost) of buildings [2]. In order to evaluate the vulnerability in urban areas, detailed building inventory, including structural types and construction levels for each building, is required. Building inventory was already prepared in UB. The existing inventory data includes structural types, construction years, building uses, numbers of stories, and building areas. However, structural types and construction years are still unknown in many buildings. Furthermore, the data lacks construction costs and construction levels for all the buildings in spite that they are necessary to assign vulnerability functions and to estimate vulnerability (repair cost) in earthquake scenarios.

In this study, we propose methodologies for estimating structural types, construction years, construction costs, and construction levels of each building using the existing building inventory in UB. These are estimated from building use, number of stories, floor area, and locations of the buildings. The construction costs are evaluated based on the procedure of the Mongolian construction code [3] using coefficients for cost per floor area, coefficients for the heating system of buildings, structural types, and floor areas. Finally, construction cost and construction level inventory are developed for assessing vulnerability in earthquake scenarios.

2. Existing building inventory data in Ulaanbaatar city

Geographical Information System (GIS) -based building inventory database in UB was firstly established by the Korea International Cooperation Agency (KOICA) in 2010. The database has been updated by the UB city office and has been used in seismic risk assessment by the Japan International Cooperation Agency (JICA) [4]. The inventory data includes more than 35,000 buildings with the number of stories, main structural types, area of buildings, some new buildings constructed year, and location information.

There are three issues obtained in GIS data. At first, building a heating system connection is unknown. Second, there are more than 20,000 buildings with missed construction year. And third, 17,000 buildings structural types are classified as unknown. This information needs to be estimated to evaluate construction costs for each building and to assign vulnerability functions.

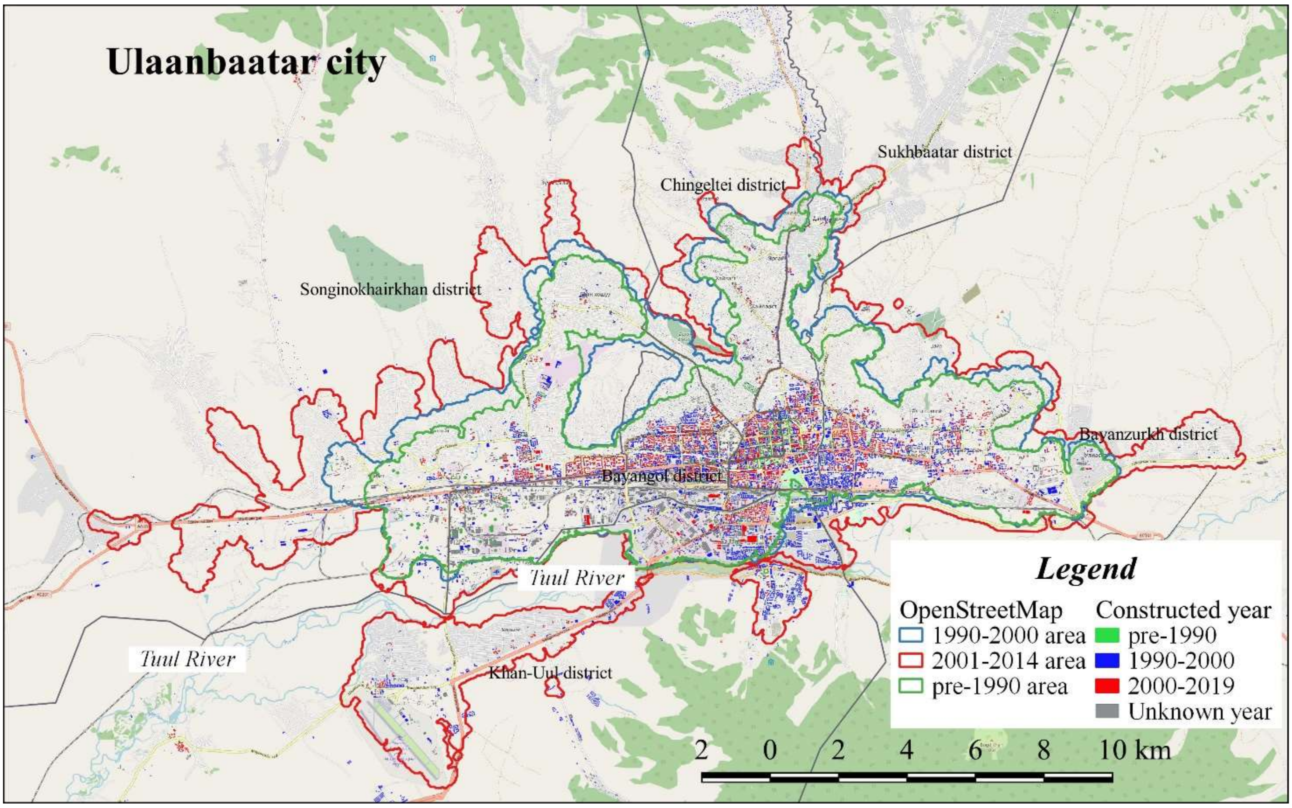


Fig. 1 - Construction year distribution in Ulaanbaatar city with urban expansion

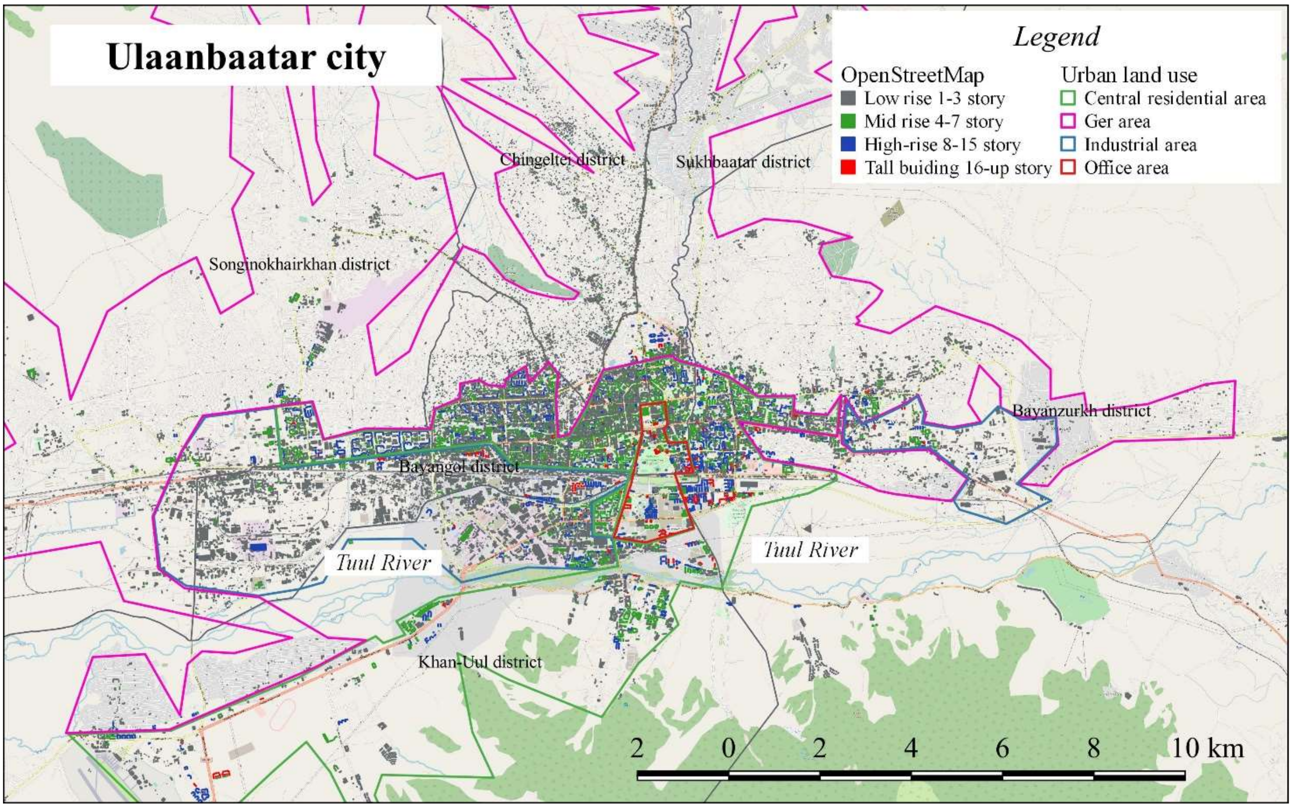


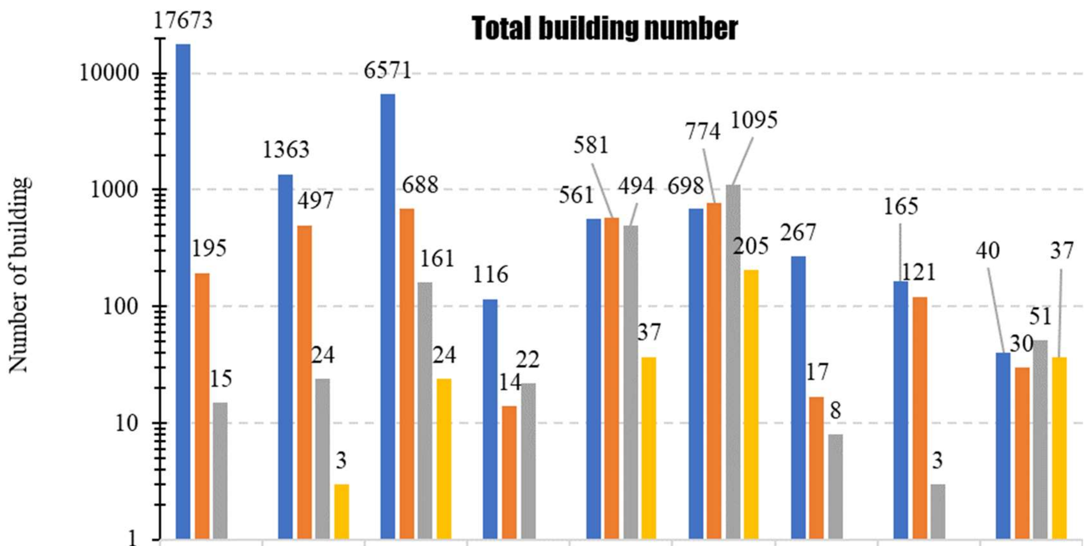
Fig. 2 - Distribution of building heights with urban land use

Fig. 1 shows the distribution of the buildings in UB with constructed year information and expansion borders of the city in 1990, 2000, and 2014. Most of the buildings are located in the central part of the city, and the northern side of the town has a large area of Ger (traditional Mongolian house) district. After 1990, the Ger district is greatly expanded, especially in the mountain area. There are usually small houses and ger districts. Based on construction year data, many new buildings are constructed after 1990 in the central part of UB. Due to building density increased several times, significant issues such as traffic, pollution, and vulnerability of earthquake risk increased.

Fig. 2 shows the height distribution of buildings with the use of urban land. The ger areas are dominated by low-rise buildings, with mid-rise and high-rise buildings appearing well throughout the city. In particular, the central office and residential areas are highly concentrated in high-rise buildings. We can see that the tallest buildings are concentrated in the center of the city near the Tuul River.

Fig. 3 shows the number of buildings in the inventory data according to structural types and building heights. The structural type of many low-rise buildings is unknown. Finding these buildings by approximate types of structures, and the number of buildings with brick and wooden load-bearing structures seems entirely erroneous. For example, a large number of buildings are more than five stories high in masonry. And the height of the three-story wooden building is considerable. So when first recording this data, the main bearing structure was incorrectly listed as wooden or brick if the roof or exterior wall non-supporting structure is wooden or brick.

Despite the errors in the existing inventory data, the building distribution in UB suggests that typical building types can be characterized by other building information such as the location of buildings, building use, building area, number of stories. In this study, the construction years and structural types for the unknown buildings are estimated through the analysis of the building characteristics in the existing building inventory.



	0 Unknown	1 Brick	10 Timber	12 Concrete	2 Precast	3 RC	4 Steel	7 RC brick wall	9 RC wall
Sum of 1-3 story	17673	1363	6571	116	561	698	267	165	40
Sum of 4-7 story	195	497	688	14	581	774	17	121	30
Sum of 8-15 story	15	24	161	22	494	1095	8	3	51
Sum of 16-up story	0	3	24	0	37	205	0	0	37

Structural types

Fig. 3 - Number of buildings with structural type and number of stories in existing inventory data

3. Updating of building inventory data

Simple algorithms are developed for estimating construction years and structural types for the unknown buildings in order to update the GIS data. Fig. 4 shows the algorithm of the estimation of construction years. If the structural type of the target building is timber or precast, the construction year is classified into an older building constructed before 1990. If the number of stories is higher than 12 and the structural type is RC, or the building is located in the area developed after 2000, the construction is classified into a newer building constructed after 2000. Other buildings are classified to the buildings constructed between 1990 to 2000.

Fig. 5 shows the flowchart for the estimation of structural types for the unknown buildings. The buildings are classified to Masonry, Timber, Precast, RC, and Steel frame considering building area, width, length, building location, and the number of stories. The small and low-rise buildings are basically classified into Masonry or Timber structures. Large and higher buildings are classified as Precast, RC, or Steel frame structures. If the buildings are located in the industrial area, the buildings are classified as the Precast or Steel frame.

The estimated structural types are validated by comparing it with the field photographs. Fig. 6 shows the comparison of the photographs of typical buildings in Google Maps and the structural types estimated by the proposed method. These two buildings are classified as unknown in GIS data; after modification, structural types are RC and precast. The results show that the estimated structural types agree with the conditions of the actual buildings.

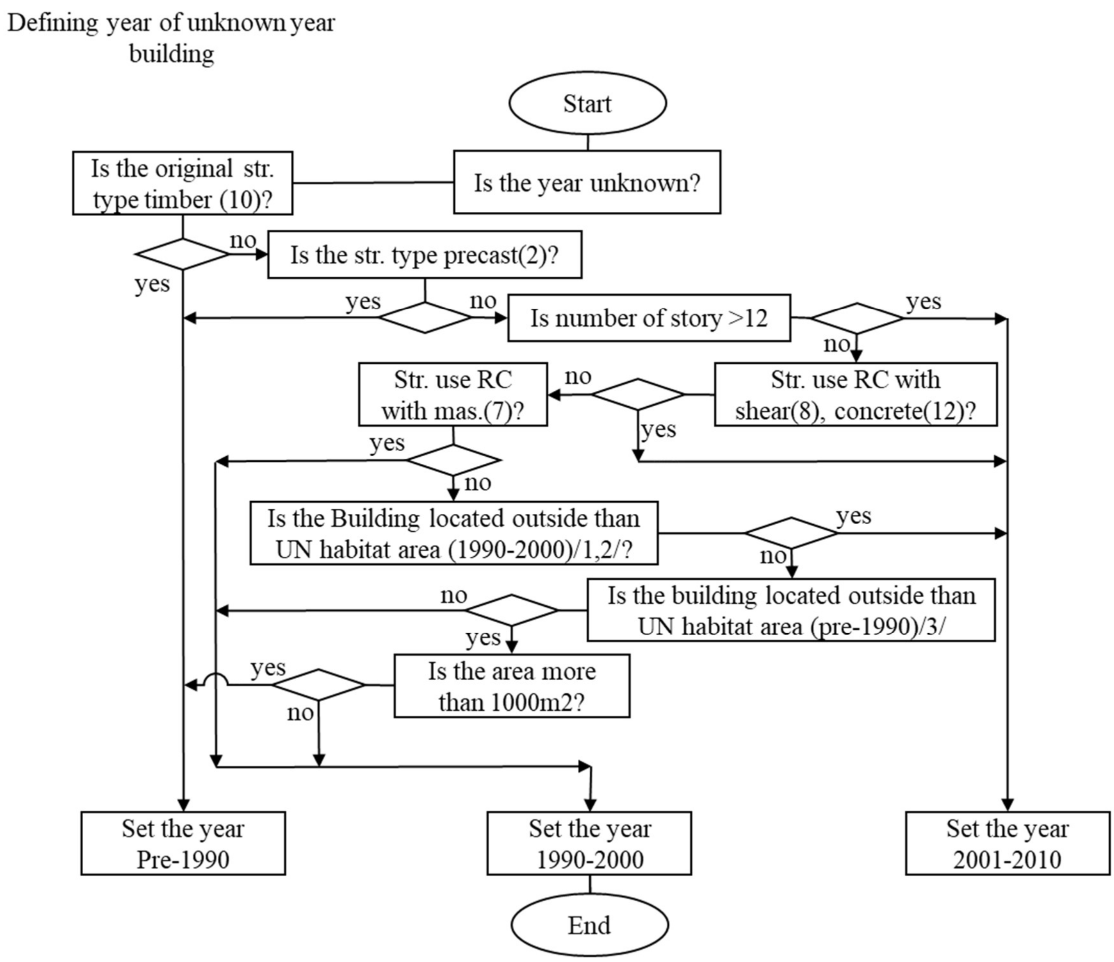


Fig. 4 - Flowchart of defining construction year.

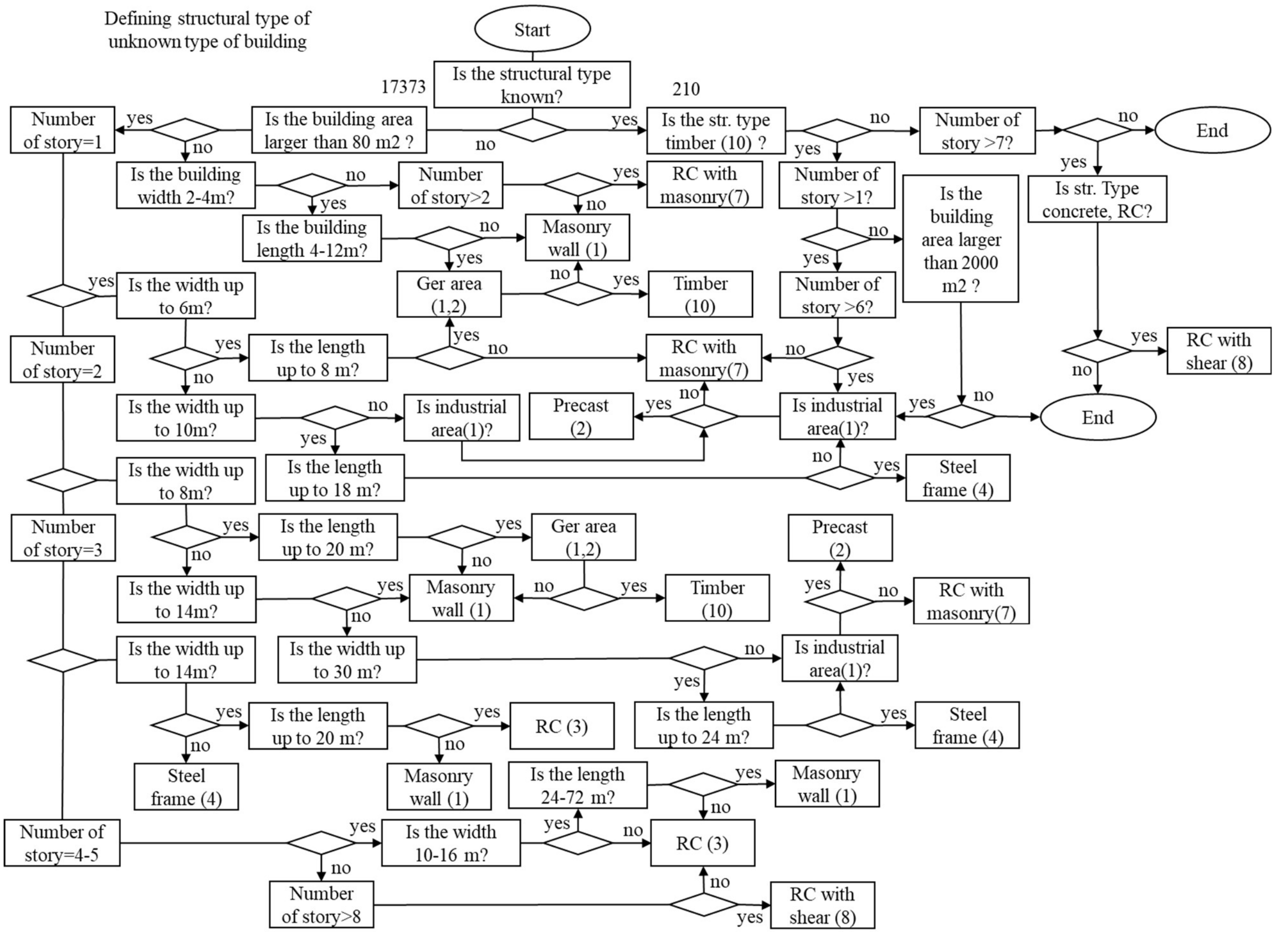


Fig. 5 - Flowchart of identifying the structural type.

Fig. 6 - Comparison of estimated structural types and field photographs in GoogleMaps.

4. Estimation of construction costs

The building cost of Ulaanbaatar city is estimated using Mongolian construction code "Construction unit cost" (BD81-106-16) [3]. The latest revision has confirmed in 2016, which is suitable for this research data. The total cost depends on the area of the individual building and other coefficients of local conditions, such as building heating system, location, inflation rate, and outside wall types, which is shown in Eq. 1.

$$\frac{Cost}{(MNT)} = cost\left(\frac{MNT}{m2}\right) * area(m2) * K_{nature}(GIS) * K_{distance}(GIS) * K_{heating} * K_{economy} * K_{reduction} \quad (1)$$

$$Total\ cost = \frac{Cost}{(MNT)} * (1 \pm i)^n \quad (2)$$

$cost(MNT/m2)$ – Building unit cost per floor area (1.0 USD = approximately 1550 MNT /2016/)

$area(m2)$ - Building floor area meter per square

$K_{nature}(GIS)$ - coefficient of natural influence from the soil, weather. BD81-106-16 2016, I-1 (Central area of UB), II-1.05, III-1.10, IV-1.18, V-1.25 [3]

$K_{distance}(GIS)$ – coefficient considers transportation fee BD81-106-16 2016 [3]

$K_{heating}$ - Coefficient considered a heating system for each building. BD81-106-16 2016 [3]

$K_{economy}$ – Coefficient considered the economic condition at each year BD81-106-16 2016 [3]

$K_{reduction}$ – Coefficient of reducing area considered with outer wall space in Table 4 [3]

i- yearly cost increment 2013

n – a year from 2013 BD81-106-16 [3]

$i_{2013} = 1.0 \ \ i_{2014} = 1.03 \ \ i_{2015} = 1.02 \ \ i_{2016} = 1.04$

In this research, the target area is central districts of UB city, that's why all the buildings are under 50 km far from UB, the coefficient $K_{distance}$ is 1.0. According to BD81-106-16 [3], the coefficient $K_{natural}$ is 1.0 at the central district of UB.

Residential apartments are connected to the central heating system in central regions of UB. Most of the households located around mountain areas are not connected to the city system. Since it is difficult to find information about the engineering system coverage map of UB, the coefficient $K_{heating}$ is estimated from the updated GIS data by defining the engineering system connected area of UB. Fig. 7 shows the flowchart for identifying a heating type for each building. The heating type is determined from the location of the building, structural type, building area, and construction year. The smaller coefficient is given to the buildings with a simple heating system, and a higher coefficient is given to the buildings with the central heating system. Fig. 8 shows the distribution of the estimated heating types in UB.

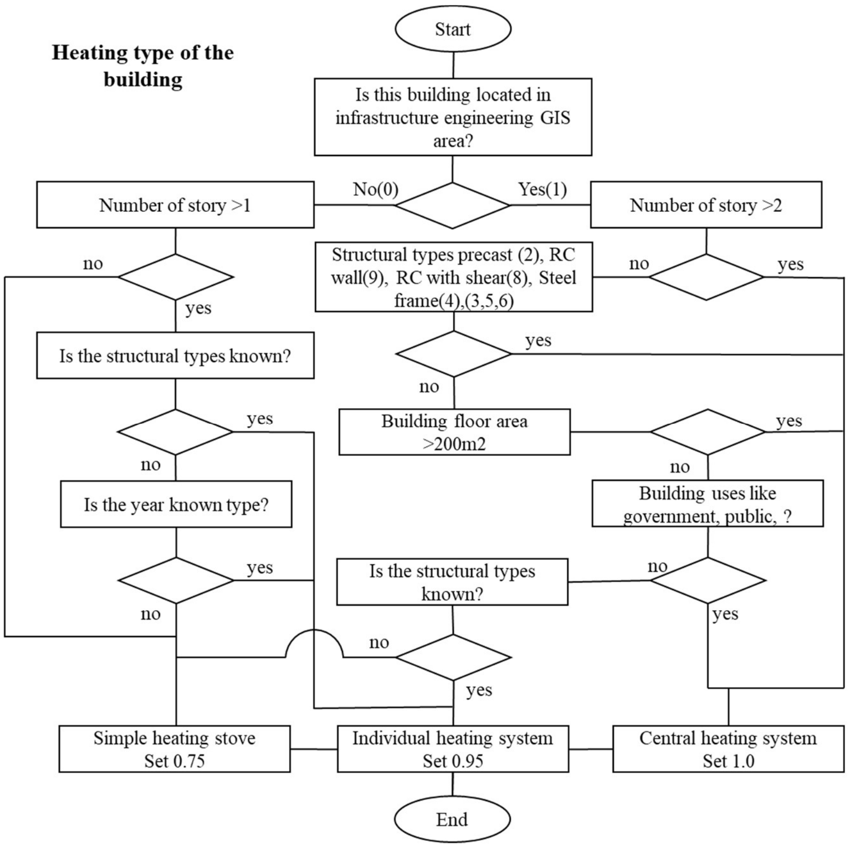


Fig. 7 - Flowchart of heating type of building

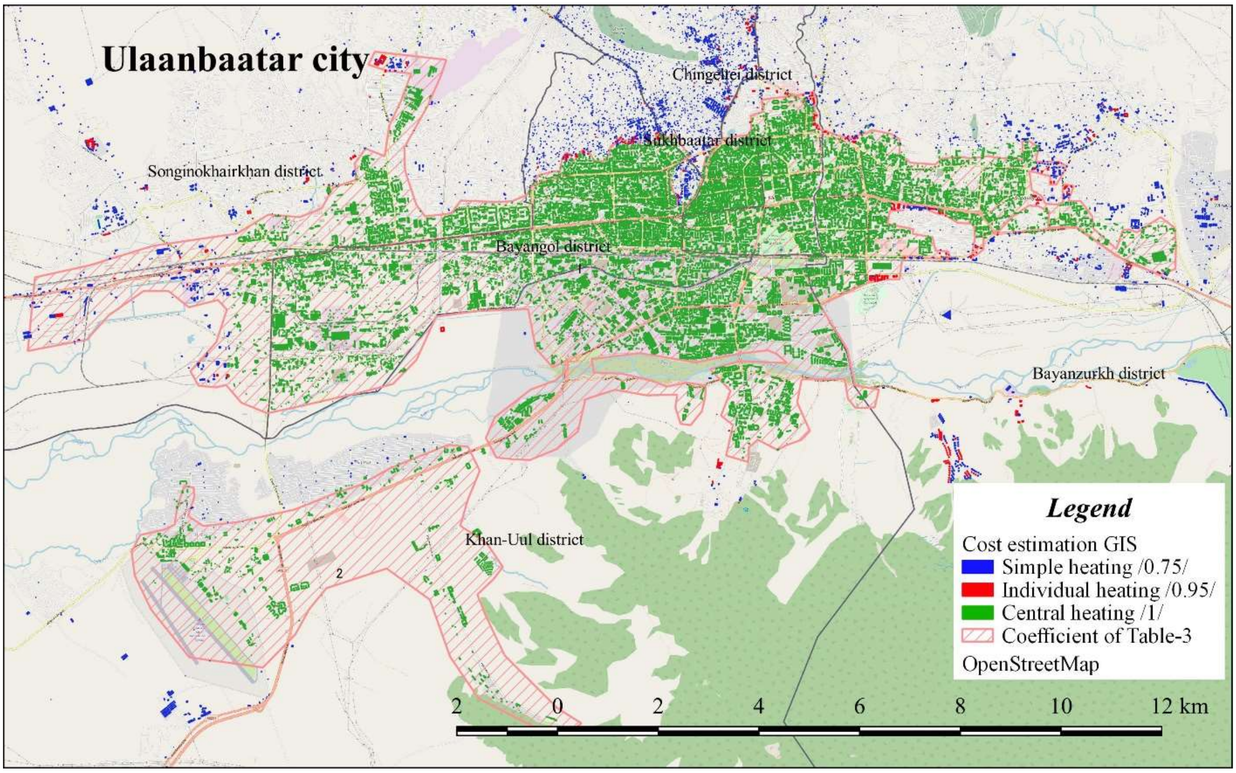


Fig. 8 – Identified heating type coefficient of buildings in Ulaanbaatar city

Fig. 9 shows the distribution of the estimated building cost in USD based on the Construction unit cost code. Ger district is located north side of UB; thus, there are a large amount of lower price buildings estimated on the map. Fig. 10 shows the histogram of the cost of construction. As you can see, the estimated cost of buildings less than 20,000 USD is more than 6,000. Building costs up to 40,000 USD is about 5700. Buildings cost up to 60,000 USD is about 2800. About 60% of the buildings cost less than 60,000 USD, and about 80% cost less than 26,000 USD. 90% will cost less than 500,000 USD.

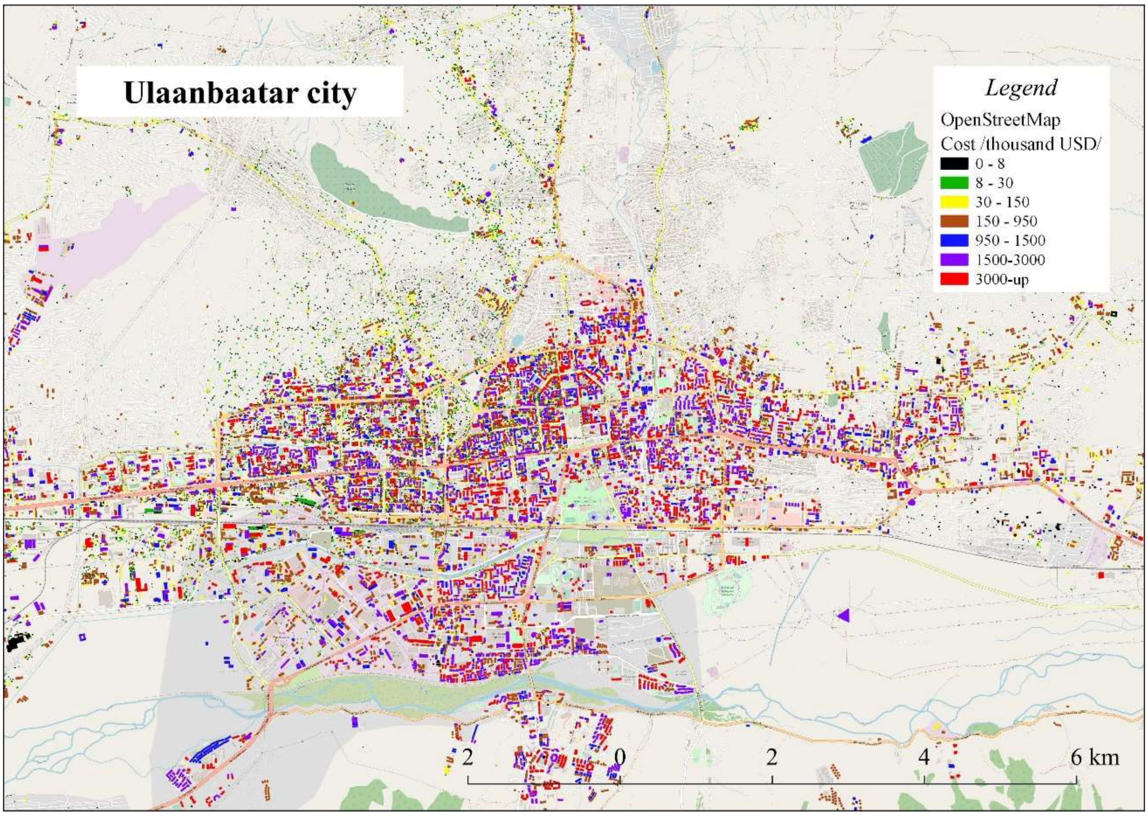


Fig. 9 - The construction cost distribution in UB

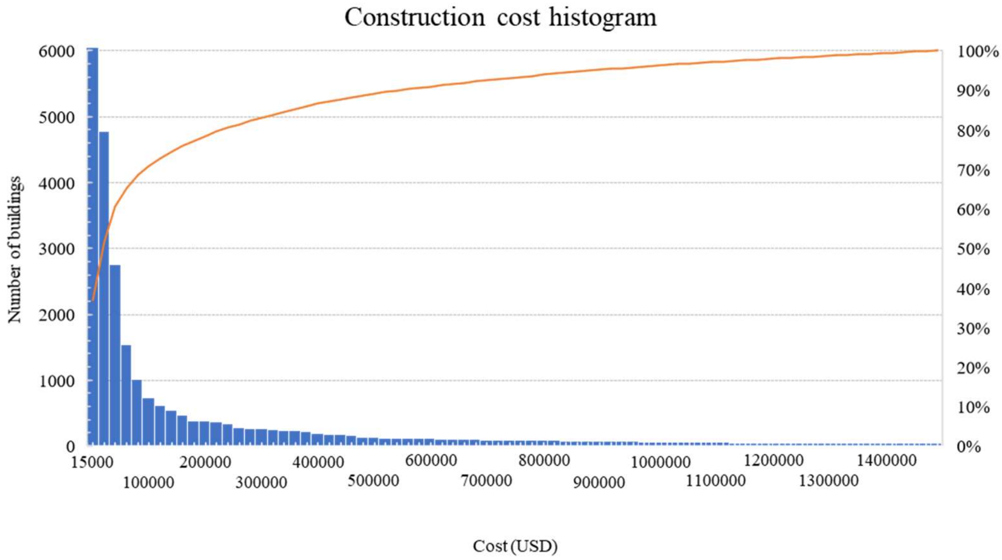


Fig. 10 - Construction cost histogram number of building

5. Vulnerability function assignment

In order to estimate building damage and economic loss due to a scenario earthquake, vulnerability functions for all the building types in UB are required. Developing vulnerability and fragility curves are the most critical challenge, but there was not any severely damaged building data from the real occurred earthquake in and around the UB area. Recently vulnerability functions for all the considerable building types in the world were proposed in the Global Assessment Report (GAR) [2] to assess seismic risk for buildings. Therefore, the vulnerability functions for the structural types evaluated in GAR are employed in this study.

In order to assign the vulnerability functions to the buildings in UB, the quality of construction (High, Medium, Low, and Poor) needs to be given to the buildings. Fig. 11 shows the flowchart for assigning structural types in GAR and the construction quality level for low-rise Masonry buildings. The construction year, building area, building use, and building location are used in the estimation. The buildings are classified to RM1L (Reinforced masonry bearing walls with wood or metal deck diagrams) or URML (Unreinforced masonry bearing wall). Such classifications are applied to other building structures.

Fig. 12 shows the distribution of the construction level with the structural type of GAR. We can see that poor levels are usually located in the suburbs and ger districts. Blue has been noted for the high-quality buildings that have been recently built around the city area. Buildings of medium quality and slightly outdated brick bearing structures of green color are often noted. However, small buildings of brick and brick suburbs and small buildings in residential areas are grayed out below average. The vulnerability types of building structures are shown in Fig. 13. The brown color is noted masonry buildings, and they appear to be scattered throughout the suburbs and Ger districts. However, reinforced concrete structure buildings were marked in green and were located mainly in residential and central areas. Red is marked prefabricated buildings and can be seen in industrial and residential buildings. Based on Fig. 12 and 13, it is now possible to evaluate the seismic risk of all the buildings in UB. The economic loss of the buildings in UB due to a scenario earthquake would be assessed in the future work.

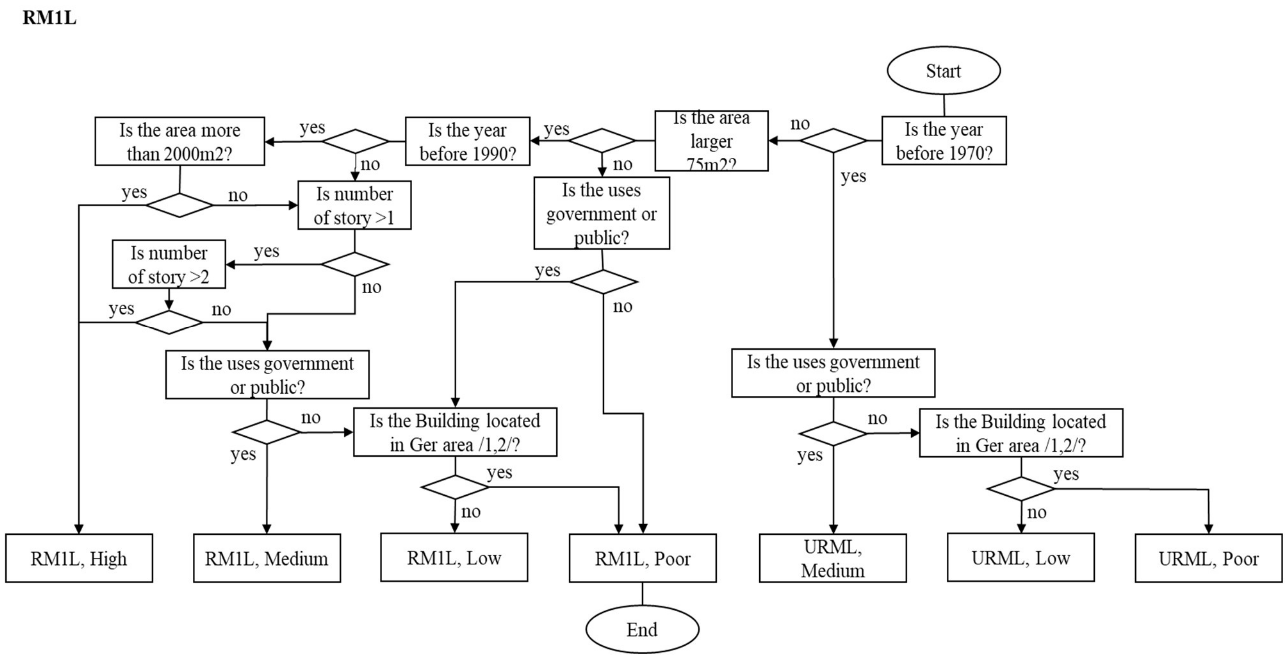


Fig. 11 - Flowchart of the vulnerability level of the building

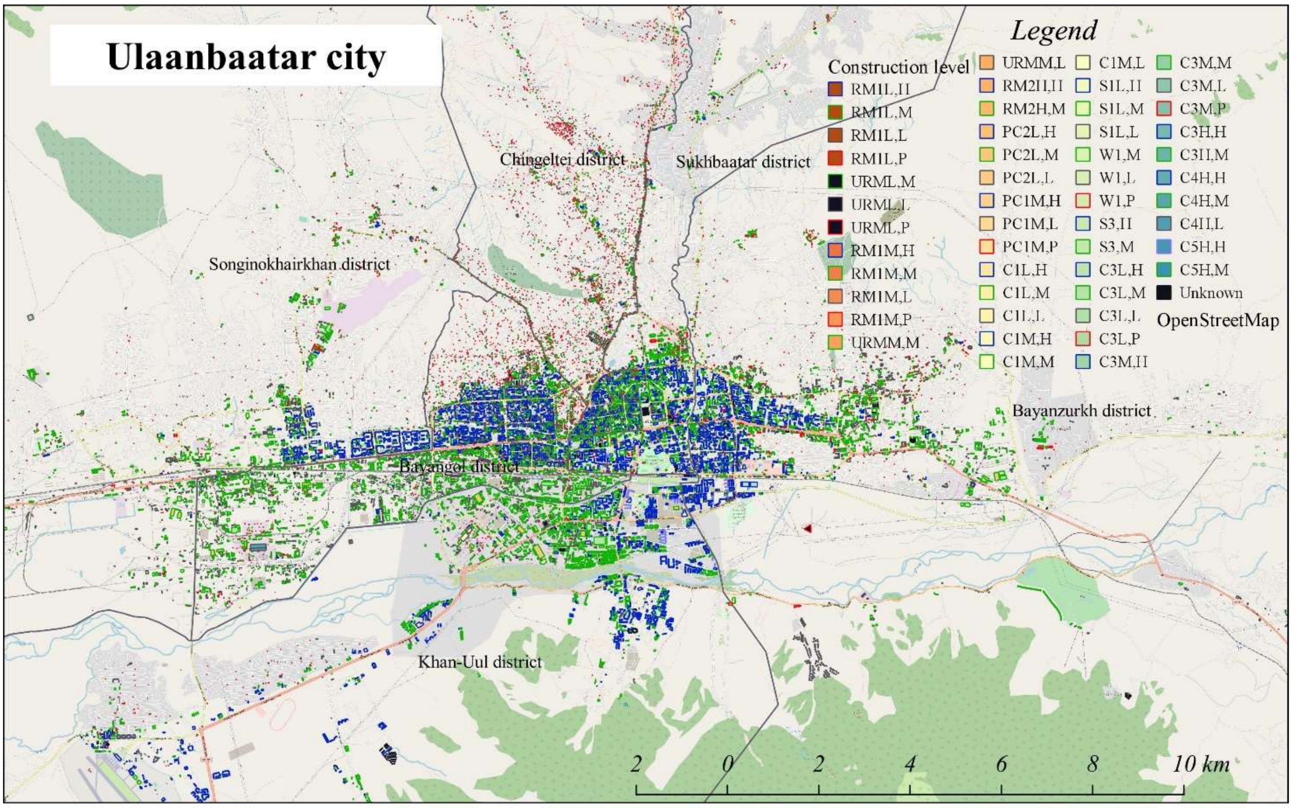


Fig. 12 - Construction level of Ulaanbaatar.

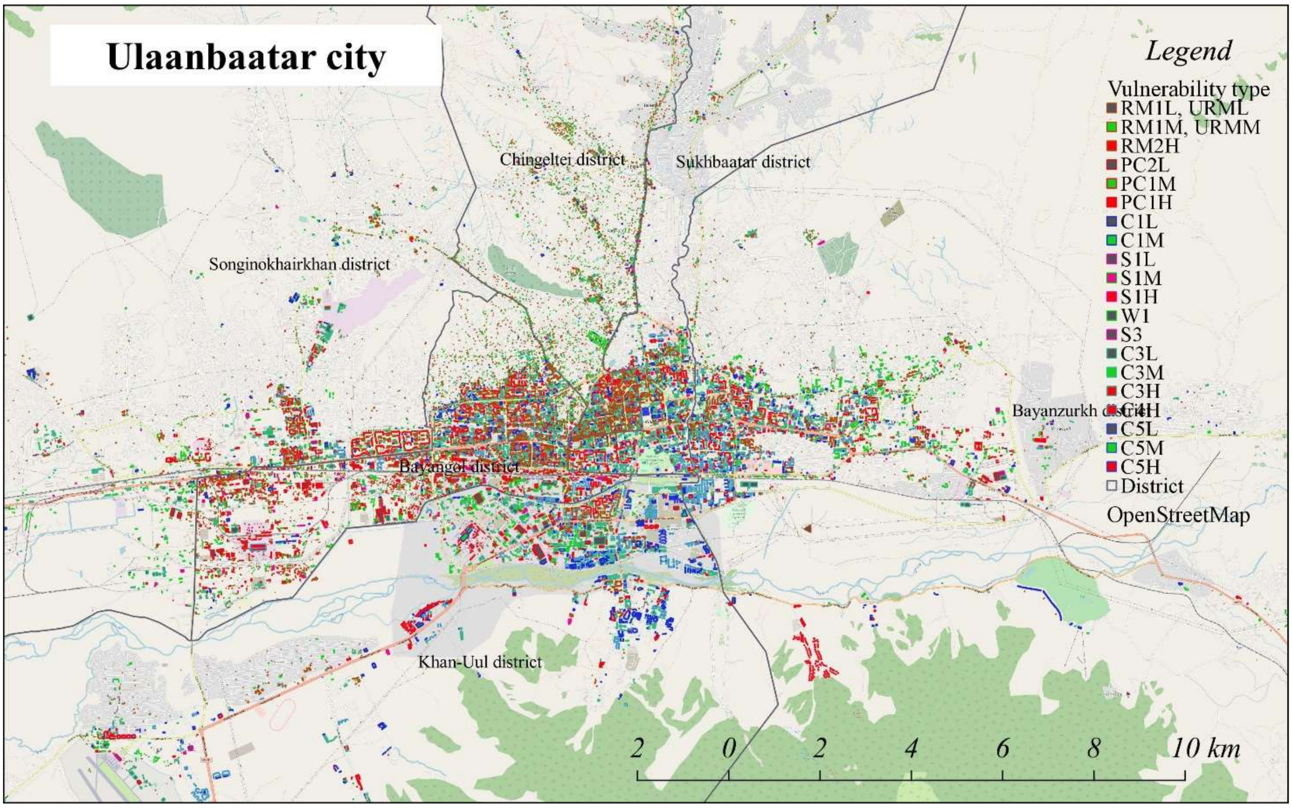


Fig. 13 - Types of vulnerability location of Ulaanbaatar.

6. Conclusions

In this paper, we introduced algorithms for estimating construction year and structural types for the unknown buildings in Ulaanbaatar city, Mongolia, through the analysis of the existing building inventory data. We confirmed that the estimated structural types show good agreement with the actual buildings. The construction costs of the buildings in UB are estimated based on the updated building inventory data and the Mongolian construction code. The vulnerability functions by GAR are also assigned to the buildings considering structural type, building height, and construction level.

Which is necessary for the next step of earthquake damage estimation of Ulaanbaatar city. The purpose of this study is to provide a key database for assessing the economic result of earthquake risk in Ulaanbaatar. Specific evaluation of building data based on their experience and capabilities is essential for future research. Ulaanbaatar has been growing rapidly since 1940, and its population density has grown year by year, increasing the density of its buildings to larger ones. Buildings built between 1960 and 1990 were often constructed with proper design oversight, but since 1990 they have been significantly reduced in quality due to significant alterations and adverse changes in main structural members. Since the 1990s and especially the 2000s, the development process has been very different, with good quality buildings with new technologies as well as various structures with poor design features such as non-design materials. For future research, it is planned to base the previous research on strong earthquake propagation and estimate economic damage to the building.

7. Acknowledgment

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8. References

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