Investigation and Analysis of Existing Housing Deterioration in Jinan

Xiao Wang\textsuperscript{1*}, Bing Li\textsuperscript{2}, Xiwen Zhang\textsuperscript{1}

\textsuperscript{1} School of Civil Engineering and Architecture, University of Jinan, Jinan, Shandong, 250022, China
\textsuperscript{2} Tongyuan Design Group Co., Ltd. Jinan, Shandong, 250022, China

E-mail: xiaowang2010@126.com

Abstract. This article takes existing houses in Jinan as a research object, focuses on the outer walls of the houses, and conducts field surveys and collections of the existing housing deterioration phenomena. Based on a large amount of survey data, the existing housing deterioration phenomena and the distribution characteristics are analyzed, and combined with the research of previous literature, the reasons for the deterioration phenomenon were discussed from the four aspects of design and construction, construction quality, materials selection, and maintenance.

1. Introduction
China has been carrying out a large number of commercial housing construction since the 1980s, and the quantity and quality have been improved. After nearly 40 years of usage, a large number of houses have entered the stage of medium or even major repair, which means the period of housing repair and renewal is coming. According to incomplete statistics, about 3.5 billion square meters of existing residential buildings in cities and towns in northern heating areas need to be repaired\textsuperscript{(1)}. Since the “11th Five-Year Plan” began to promote the renovation of existing residential buildings in China, large-scale renovations have been carried out on old houses built in the 1980s and 1990s, and the overall appearance of the houses has been greatly improved. However, the specific content of most existing residential renovations is mainly to add an insulation layer to the outer wall, and to decorate the facade outside the insulation layer, and some houses have replaced the external windows. The outer wall decoration has a great effect on the improvement of the overall image of the residence and the residential area, and has improved the deterioration like the facade and dirt of the residence. However, due to the disadvantages of the overall renovation method and the difference in construction level, there are still many decorative deteriorations in the houses that have been reconstructed.

This article considers that the appearance of deterioration in different parts of a house has different formation mechanisms, functions and corresponding repair methods. Therefore, it is very important to scientifically investigate and analyze the deterioration phenomenon of exterior decoration surface of the existing residential buildings as the basic work of renovation.

2. Overview of Existing Homes in Jinan
Under the influence of national policies, after 2000, Jinan City's policies on residential restoration and renovation have been strengthened in terms of quantity, intensity, and pertinence. A number of renovation activities were carried out for the existing residential areas in the 1980s and 1990s.
From 2005 to 2007, Jinan City began to carry out special renovations on 153 residential quarters built before 1999[2]. In December 2008, Jinan City issued the “Notice on the assignment of heating metering and energy saving renovation of existing residential buildings in Jinan”. In 2011, the “Implementation opinions of the people's government of Jinan city on promoting the reform of heating metering and energy-saving renovation of existing buildings” was promulgated. During the "11th Five-Year Plan" period, Jinan city completed 46 heating metering and energy-saving transformation projects of existing residential buildings, involving 439 buildings and 19,562 households, with a total construction area of 2.4007 million square meters; during the “12th Five-Year Plan” period, about 15 million square meters of energy-saving renovation of existing buildings was realized[3]. In 2018, the “Implementation plan for the renovation and renovation of old residential quarters in Jinan city in 2018” was promulgated, and 461 residential quarters were renovated[4]. In 2019, 358 existing residential districts were renovated. The content and standards of the renovation mainly include the improvement of public security prevention and control and fire protection facilities, illegal facilities cleaning up and sanitation facilities completing, community environmental facilities improvement, community infrastructure renovation, and water, electricity and heating professional facilities renovation[5].

2.1 Selection of survey objects

Residences are mainly composed of four parts: main parts, supporting parts, supporting technologies, and special facilities. From the perspective of the life cycle of the house, the life of the maintenance parts system is 10~25 years. The exterior protection components of the residences built in the 1980s and 1990s have now exceeded or approached their useful lives. Considering with the lagging and extensive repairs of maintenance and management, the aging of this part of the residence has worsened. The significance of collecting and organizing disease information for this part of the houses is even more significant. Therefore, among the objects surveyed in this research, the proportion of houses built in the 1980s and 1990s is relatively large.

The study mainly selected five representative existing residential renovation communities in Jinan as the survey objects, namely Qilishan Community, Langmaoshan Community, Wangguanzhuang Community, Leshan Community, and Fenglin Community (as shown in Table 1). By establishing examples of typical existing houses, maintaining the status quo, clarifying the research objectives, visiting the property management department and the real estate department, the common deterioration phenomena and repair methods of existing houses were known. Then, through the methods of photo taking, field surveying, questionnaire survey, and professional interviews, a comprehensive understanding of the existing phenomena related to the deterioration of the house were obtained.

| Community name  | Qilishan Community | Langmaoshan Community | Wangguanzhuang Community | Leshan Community | Fenglin Community |
|-----------------|--------------------|-----------------------|--------------------------|-----------------|------------------|
| Construction Time | 1980               | 1993                  | 1995                     | 1990            | 1996             |
| Structure Type   | Brick concrete structure | Brick concrete structure | Brick concrete structure | Brick concrete structure | Brick concrete structure |
| Floors           | 5                  | 5                     | 6                        | 6               | 7                |

Table 1 Overview of five representative research communities selected

![Picture of Qilishan Community](image1)

![Picture of Langmaoshan Community](image2)

![Picture of Wangguanzhuang Community](image3)

![Picture of Leshan Community](image4)

![Picture of Fenglin Community](image5)

Site Plan of Community

![Site Plan of Qilishan Community](image6)

![Site Plan of Langmaoshan Community](image7)

![Site Plan of Wangguanzhuang Community](image8)

![Site Plan of Leshan Community](image9)

![Site Plan of Fenglin Community](image10)
2.2 Collection of deterioration phenomena

The collection of deterioration phenomena is difficult to specifically limit in terms of the size and scale of the deterioration, but it can reflect some characteristics and laws of the deterioration phenomenon of the house from the side, and thus has a more accurate grasp of the overall state of the house.

Among the many deterioration phenomena, the more common deterioration phenomena with higher incidences were finally selected: damage, cracks, dirt, peeling, mold, etc. In the collection position, there are several parts such as the outer protection structure, public space, facade doors and windows, and equipment platform. In view of the above-mentioned deterioration phenomena, and based on the literature and relevant cases of field investigation, several typical deterioration phenomena and locations of external walls were briefly explained (as shown in Table 2). The collection of typical deterioration phenomena of existing houses listed in the table has become the main content of investigations.

Table 2 Several typical deterioration phenomena and parts of exterior walls

| Damage | Crack | Dirt | Peeling | Mold |
|--------|-------|------|---------|------|

**Damage:** It occurs frequently at the corners of the building and is related to the type of building materials and man-made damage.

**Crack:** Generally, it refers to the phenomenon that the outer wall (mostly the structure interface) is damaged due to changes in temperature and humidity, improper construction or internal stress, and the material surface is cracked. The generation mechanism is mainly as following two reasons: the tensile stress and deformation of each material layer formed under the influence of environmental conditions, when it is constrained by adjacent material layers, cracks and damage occur; due to the unreasonable internal force , uneven settlement is occurred, and cracks and damage are formed.

**Dirt:** It refers to the phenomenon that the surface of buildings is polluted by man-made or natural factors. The specific formation process usually are that: the building surface is attached with pollutants and dust, as the rain washing, then the decorative layer is polluted; after the iron components of buildings rusting, such as vertical plates and embedded hardware, the decorative surfaces of buildings deteriorated caused by rain; Man-made graffiti cause the formation of pollution on the surface of the building.

**Peeling:** It is one of the common deterioration phenomena of exterior wall coating materials, which refers to the phenomenon that due to improper construction methods or inadequate adhesion of the decorative material to the structure, the cement mortar layer appears to cause the decorative material to peel off, even detach from the structure, and fall. This peeling phenomenon has different characteristics depending on the size of the facing bricks, the different construction methods and methods of sticking, and the difference in the service time of the building.

**Mold:** This is due to the long-term adhesion of water or moisture, which causes the phenomenon of microbial growth and moss on the outer skin of the building. It usually appears most often on windowsills, eaves, awnings, under balconies and air-conditioning drains.

3. Analysis of deterioration of existing houses

3.1 Quantitative characteristics of deterioration

By sorting the collected illnesses, the total number of all types of illnesses was accumulated and analyzed (as shown in Table 3). It can be seen that the overall number of problems has a high incidence of dirt, accounting for 56% of all phenomena, more than half; cracks account for 25%, and the least phenomenon is moldy, which is only 3%. The proportion of deterioration of exterior walls with different facing materials is also very different: the frequency of cracks in paint facing exterior walls is 32%
higher than that of the other two facing outer walls; the incidence of skin peeling of outside wall is 8% and 6% higher than the paint exterior wall, respectively. The incidence of damage in water-washed stone exterior walls and paint-decorated exterior walls is 18% and 13%, which are higher than that of brick-clad exterior walls. The incidence rate of mold is the lowest among all kinds of exterior walls.

It can also be analyzed through Table 3 that the occurrence of residential phenomena has different differences according to different decorative materials. The problems with a high incidence of paint-decorated residential exterior walls are dirt, crack, damage, peeling and mold; the most common phenomena of residential facades with brick-surface finishes are dirt, cracks, peeling, damage, and mold; In the phenomena of whitewash stone external walls, the dirt, peeling, damage are relatively higher than the occurrence rate of crack and mold. From the perspective of different phenomena, the incidence of dirt in all kinds of decorative walls is all higher.

Figure 1 High to low incidence of deterioration of exterior walls of different materials

| Proportion of various deterioration phenomena of water-washed stone facing exterior walls |
|---------------------------------------------|---------------------------------------------|
| Proportion of various deterioration phenomena of paint facing exterior walls |
| Proportion of various deterioration phenomena of brick facing exterior walls |

In the 80's and 90's of this survey, the thermal zone of the building where the house is located is a cold area, and its wall thickness is mainly composed of 240mm or 370mm thick brick walls, which has high energy consumption. The investigation found that the quantity and location of the deterioration phenomenon, the construction year, the exterior wall structure and materials are all closely related. With the same exterior wall structure and materials, the amount of deterioration increases rapidly over time, and when it reaches a certain level, it gradually increases. However, due to the influential factors of
construction, structural design, and materials, the number and severity of deterioration phenomena in different monomers are not in a single proportional relationship with the age of the building.

In the case of the same building age and the same exterior wall structure, the cracks occur more frequently in the buildings with the coating surface layer than in the tiles. In addition, among all the deterioration phenomena investigated, after comparison, it was found that the number and distribution of the deterioration phenomena are not very relevant to the structural form of the building.

3.2 Distribution characteristics of deterioration

Through the collection of the collected phenomena, the residential deterioration phenomenon is distinguished from the occurrence site, and the number of different types of deterioration phenomena that occur in different parts is classified.

### Table 4 Specific distribution of different deterioration phenomena

| Specific distribution of damage | Specific distribution of cracks |
|--------------------------------|--------------------------------|
| ![Specific distribution of damage](image1) | ![Specific distribution of cracks](image2) |
| ![Specific distribution of dirt](image3) | ![Specific distribution of peeling](image4) |
| ![Specific distribution of mold](image5) |

In terms of the overall distribution of deterioration, the longer the building age, the more widespread and widespread the deterioration appears in all parts of the building. Distribution of specific deterioration phenomena: a) Damage. Damage often occurs in the lower part of the building, at the convex corners of the building, and on the walls of the chimney holes and exhaust vents artificially cut through. b) Cracks. The main types of cracks are horizontal, vertical, oblique cracks, and network cracks. Horizontal cracks are mainly located under the roof and below the window sill (as shown in Figure 2).
Vertical cracks are mostly found on the window sill (as shown in Figure 2) of the larger window hole on the ground floor of the building. There are many oblique cracks, different sizes, and more at both ends. More. Reticulated cracks are mostly cracks caused by the shrinkage of the skin material, and they mostly appear at the gables and balcony railings on both sides (as shown in Figure 3). In the external wall with insulation layer, cracks often appear along the splicing joints of the insulation board, around the window, the part of the parapet wall, and the middle of the large-scale gable wall (as shown in Figure 4, 5). c) Dirty. The phenomenon appears more frequently in large areas such as walls, under windows, windowsills, balcony railings, and cornices. According to on-site observation, the dirt phenomenon has occurred in all parts of the building, which is a relatively common disease phenomenon. It is mainly caused by natural factors and human factors. Natural factors mainly include the adhesion and deposition of dust in the air, surface dirt, wall dirt caused by rain splashing, and wall dirt caused by other parts of the disease, such as metal parts and the dirt left on the wall after rusting; human factors include such as graffiti and advertisements appear at the bottom of the building.

d) Peeling. The peeling of exterior wall coating mostly occurred on the south side, and a few also occurred on the east and west sides, and there was less peeling on the north side and bottom layer. c) Mold. On the whole, the top and bottom of the building are more easily formed mold than the middle of the outer wall. The frequency and severity of mildew are high on the underside of roof eaves, balcony boards, under the external hanging machine of air conditioner, under the rainwater mouth and in the shade corner of buildings.

In summary, it is learned that cracks, epidermis peeling, damage, dirt and other phenomena have different frequencies in different parts. Based on the above data, combining the distribution positions of external wall disease with different materials, the following "illness-site" associations table are sorted out (as shown in Table 5).

| Defect  | Wall material | Coating | Porcelain Tile | Cement |
|---------|---------------|---------|----------------|--------|
| Damage  | Coating       | Porcelain Tile | Cement         |
| Crack   | large area wall, under the window, parapet wall, cornice | large area wall, window sill, plinth, architrave | under the window, plinth, parapet wall |
| Dirty   | multi-site    | multi-site | multi-site     |
| Peeling | large-area wall, window sill, building convex corners, moldings, lower balcony panels | building convex corners, large-area walls, cornices, windowsills | plinth, window sill, molding, balcony board |
| Mold    | cornice, under balcony, under cornice | cornice, under the window | under the window, under the daughter's wall, under the balcony |

### 3.3 Causes of deterioration

There are many factors leading to the appearance of the deterioration phenomenon. At the same time, the combination and superposition of multiple factors further aggravates the degree of the deterioration phenomenon. Through the interviews with experts and the collation of relevant literature, the causes of the deterioration phenomenon were analyzed. In the following, the causes are analyzed from four aspects: design and construction, construction quality, selection of materials, and maintenance.
3.3.1 Design and construction reason
In residential design, in order to pursue high and low building heights and rich shapes, no settlement joints are provided, which can easily cause uneven settlement of the foundation, resulting in greater stress under the deformation of the wall. When the tensile stress exceeds the tensile strength of the masonry. When it is strong, the wall is easy to crack. At the same time, inadequate design and processing of nodes such as bay windows, parapet walls, tiger windows, and selected parts of the building are also influential factors for frequent occurrence of deterioration.

In addition, improper design of a single insulation material can easily cause dew in the room. The surveyed residences are brick-concrete exterior walls, which are self-insulated by wall materials, without additional insulation layers, and the wall thickness is mostly 370mm. However, such a single insulation design often causes moisture condensation and mold at corners, structural columns and concrete floors.

3.3.2 Construction quality reason
During the construction of the house, the flatness of the base layer of the wall is not enough, the adhesive does not meet the requirements or the number of anchors and the buried depth during mechanical fixing will not meet the requirements, which will cause the crack of the outer insulation layer. At the same time, for the houses that use paint surface, the grid cloths are overlapped, tilted, or different grid cloths are used, or the grid cloth is not laid along the 45° corner of the window opening, which is also an important cause of cracking. However, in the houses that use facing bricks, the surface of the substrate is too smooth during the posting of facing bricks, and the strength of the bonding material is not enough to easily cause the facing bricks to fall off.

In the late 1990s, the number of concrete components in residential buildings increased, and the number of thermal bridges also increased. Due to improper thermal insulation construction, the problem of cold and dew condensation occurred on the wall, which mainly occurred in the outdoor floor slabs and concrete beams. Columns and surroundings. The construction unit did not pay enough attention to the thermal insulation construction of these thermal bridge parts, and did not control it properly during the construction. In particular, the joints of the wall insulation board were not tight, and the insulation board was not tightly contacted with the concrete members, which caused the cold and condensation. This will cause the insulation board to crack and fall off. In addition, the wall or the base layer is covered and painted before it is dry, or the thickness of the base layer is uneven, which is prone to shrinkage cracks. During the construction, the gap between the patch and the structural wall is not filled, and the cavity formed can easily fall off under positive and negative wind pressure.

3.3.3 Material selection reason
In today's residential construction, unqualified building materials are commonplace. The use of inferior materials is an important cause of various deterioration phenomena. If an unqualified adhesive is used, the volume of the adhesive changes greatly under the dry-wet cycle and freeze-thaw cycle, which will cause stress between the tile and the adhesive contact interface, and cause the tile to fall off. Some materials have a large porosity and are susceptible to water. Their poor anti-seepage and anti-freezing properties cause the strength and volume expansion of the base material of the outer wall, which cannot resist the weathering of the atmosphere and reduce the durability of the outer wall materials. In some projects, the construction period is too short, and the time required for block forming and curing is insufficient. Therefore, they will be sent out to the construction site for masonry. After the construction of the block with a large water content, it is easy to cause shrinkage cracks.

3.3.4 Maintenance reason
During the use of the dwelling, some of the residents opened the partition wall in the second decoration to expand the combined functional space. This approach easily caused the loosening of the wall blocks, the redistribution of the internal stress of the block, and the occurrence of wall cracks. In addition, condensation and mold must be related to air temperature and humidity. The situation that causes the
temperature and humidity of the air to reach the dew point temperature and humidity is strongly related to the living habits of the residents. In the cold winter, to prevent the severe cold from entering the house, the doors and windows are tightly closed, which may cause the indoor air to circulate. Some even dry clothes indoors, resulting indoor humidity is too large, easy to produce dew phenomenon, then water vapor outward diffusion in the wall to produce moisture, mildew phenomenon.

4. Conclusion
From the perspective of the entire life cycle of the building, the age of the residential buildings under investigation has reached the stage of intermediate repair and overhaul. This kind of arbitrary maintenance and management has further exacerbated the aging of this part of the residence. For houses with a construction age of 5 to 10 years, owing to their shorter construction age, the overall condition of the house is better, and the establishment of a daily repair system is even more significant.

The collection and analysis of deterioration phenomena in the maintenance and renovation of a house are the basic conditions for the renovation and renovation of the house. Experts' participation in the diagnosis of the deterioration phenomenon is a necessary condition to ensure the effective repair of the house. At the same time, residents' understanding and active participation in the maintenance process is also important to ensure the sustainable maintenance.

Acknowledgements
This research was financially supported by the Shandong Provincial Natural Science Foundation (ZR2017BEE074), the Key Technology Research and Development Program of Shandong Province (2019GSF111031).

References
[1] Guide for energy saving retrofit of existing residential buildings. General Office of the Ministry of Housing and Urban-Rural development of the People's Republic of China, 2012.
[2] Song R. A study on the design mode of the existing residential building regeneration. M.E, Dalian University of Technology, Dalian, China, 2010:70.
[3] Wang L. Jinan will renovate existing buildings about 15 million square meters. Available at: http://sd.dzwww.com/bwyc/201101/t20110121_6137711.html (Accessed: 21 January 2011).
[4] Implementation plan for renovation of old residential districts in Jinan City in 2018. Jinan Municipal Bureau of Housing and Urban-Rural Development, 2018.
[5] Implementation plan for renovation of old residential districts in Jinan City in 2019. Jinan Municipal Bureau of Housing and Urban-Rural Development, 2019.