Comparative study on the roofs of traditional revival architecture in modern China

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Abstract. In this paper, the traditional revival architecture works of four prominent Chinese and Western architects in China are considered for the purpose of analyzing the external form of the roof curves in conjunction with the internal function of the roof truss. The differences between Western roof truss structure and Chinese traditional one in forming the characteristic roof curves of each cases are clearly brought out. The investigation reveals the adaptive and mutual influence of the Western structural systems and Chinese architectural elements on each other, and reflects on the significant contributions of Chinese and Western architects in the modernization and transformation process of traditional revival architecture.

1. Introduction
In modern China, the story of the societal development in modern China is full of twists and turns. With the introduction of Western culture, Western architecture swarmed into the early port cities of China, such as Beijing, Tianjin, Shanghai, Guangzhou and Wuhan. Consequently, the contemporary architecture in these parts of China is a mixed exhibition of Chinese architecture, Western architecture, and Chinese traditional revival architecture. Chinese traditional revival architecture is also referred to as ‘Chinese intrinsic-style architecture’. It dates back to the 1920s, which was a period during which many of the scientific and technological design concepts of Western architecture came to be combined with Chinese traditional architectural elements. In terms of appearance, it closely resembles the Chinese traditional architecture style; whereas in terms of internal functions, it fits in with the space requirements of modern architecture. In the 1920s, ‘indigenization’ was carried out worldwide by Christianity. As a result, the architectural design of schools prominently shows a combination of Western roof truss and Chinese traditional roof profile. The architects Henry Killam Murphy (1877-1954) and Dom Adelbert Gresnigt (1887-1956) may be considered as representative of this movement. Murphy combined Chinese traditional architectural style with the modern Western architectural concepts and designed several beautiful campus buildings with the combination of Chinese and Western elements, those universities being strikingly representative of his style. Dom Adelbert Gresnigt was a missionary architect with art training background. By visiting and studying Chinese indigenous architecture, he had gathered a good understanding of Chinese traditional art. He designed and built four significant seminaries: the main building of Catholic University of Peking, Regional Seminary of Kaifeng, The South China Regional Seminary, and the Seminary of the Disciples of the Lord. Modern architects also made exploratory contributions to traditional revival architecture. For example, Sicheng Liang and Tingbao Yang, who studied in the University of Pennsylvania, United States, had good understanding of the precepts of Western architecture. Their works of Chinese traditional revival architecture had a
great representative significance, combined the culture and art of their nation with Western concepts. The National Central Museum of China was the first ‘great roof’ building designed by Mr. Liang. Mr. Yang contributed to numerous works and created several modern buildings in Beijing and Nanjing with Chinese characteristics by employing Western design concepts in combination with Chinese art. The explorations and contributions of the above mentioned architects have driven, in a significant way, the modernization and transformation of Chinese architecture. In the context of the important works of the four architects mentioned above, this paper discusses the various forms of roof curves employed in traditional revival architecture, with special emphasis on the structure and construction features of the constituent curves.

2. Design of roof curve
The roof profile is the focus of the external form in this paper. This section compares the external roof appearance characteristics in the representative works of the four architects mentioned in the previous section.

2.1. Roof curve in the work of Henry Killam Murphy
Gingling College, built in 1919-1923, is a representative work of Murphy. This building made a great breakthrough in the single building form of architecture. In the past, when imitating Chinese ‘great roof’ buildings, Western architects mostly imitated the independent hip roof or gable-on-hip roof in official buildings. However, the architectural style of the roofs of Gingling College appears to be prominently Chinese-style gable-on-hip type. Among the seven buildings built in the first batch, the roof of No. 100 building in the main complex has the most special design. Its roofs are formed with the combination of three gable-on-hip roofs, appearing high in the middle and low on both sides, and are flat and straight for the most part, with only the eaves and corners upturned, which can be considered as a simplified imitation of the Chinese style. A skylight protruding slightly above the roofing is added in lateral gables of the middle part of the roof, facilitating daylight and ventilation. The building facade is of the typical three-level type commonly followed in Western architecture, comprising podium, order, and roof. The main buildings in the middle have a roof-height to wall-height ratio of 3:4, whereas the side buildings feature a ratio of 1:1 (Figure 1). These ratios are indicative of the control of proportional relations in the facade typically observed in Western architecture. The No. 100 buildings are the main buildings lying on the campus axis, and the combination of high and low roofs on these buildings is an attempt of traditional revival architecture. Thus, it can be seen that Murphy consider the combination of roofs as a means of highlighting the importance of a building, especially the one on the main axis.

![Figure 1. Elevation of No. 100 Building of Gingling College](image)

2.2. Roof curve in the work of Dom Adelbert Gresnigt
The church buildings designed and built by Dom Adelbert Gresnigt in China combined the elements of
Western rationalist architectural style with those of the Chinese traditional one. Their plans were always enclosed, focused on the internal activity. The construction for Gresnigt’s works was mostly carried out under the cooperation of Société d’Exploitation des Établissements Brossard-Mopin, a French company. The buildings are of superior quality construction. Both the overall form of the structure as well as the details shows creative originality. A comparison of the design drawings and the on-site building conditions clearly showed the positive example made by the architect to make the Western roof truss system fit in with Chinese traditional architectural style — the combination of the Western Howe truss with Chinese-style roofing to create the appearance of Chinese-style roof with juzhe curves. The roofing of Regional Seminary of Kaifeng on the other hand combined the characteristics of traditional vernacular houses in South China, which generally adopted gable roofs (Figure 2). Additionally, the buildings were surrounded by a single-wrapped eaves gallery, while Guanyindou gable wall and step gable were incorporated in local parts. While these architectural details did not show the local characteristics of Henan, China, it is evident that through his frequent visits and interactions with the local culture as well as through dedicated study, Gresnigt obtained unique insights into the local Chinese architecture art, and made many attempts to weave local architectural elements in his designs. The main buildings in Seminary of the Disciples of the Lord supported a hip roof, with smooth roof curves of greater curve radius, with the cornices conspicuously upturned (Figure 3, 4). The roof curve profile shows little resemblance to Chinese traditional ‘juzhe’ method. The roof curve comprises three-section broken lines formed from reinforced concrete. The appearance of the roof clearly seeks to emulate the concave roofing of Chinese traditional architecture, reflecting the creativity of Western architects.
in exploring the combination of Western-style roof truss and the roof of Chinese traditional architecture.

2.3. Roof curve in the work of Sicheng Liang

After returning to China, Sicheng Liang, an expert in the history of Chinese ancient architecture, led the members of Chinese Architecture Society for the study in extensive field investigations and mapping of Chinese ancient architecture. Liang was involved in the design of The National Central Museum in Nanjing, which is Chinese traditional style with a heavy emphasis on the official standards. The overall architectural shape, composition mode, and structural details followed the pattern of traditional architecture, presenting the unmistakable impression of an ancient palace (Figure 5). The roof of the National Central Museum is a hip roof, designed by the method of ‘tuishan’ (Pushing-out gable, extended ridge and purlin) first introduced in Yingzao Fashi (Method to determine pitch and curvature of roof). The technique involves lengthening the main ridge and increasing the slope of roofs on both sides. The four hips appearing right-angled on the horizontal projection of roof were made to become curves, and hips seeing from the facade were made to curves as well. The roof curve was designed by the ‘juzhe’ method, and was also exaggerated, with the depressing height ratios of 1/7.7, 1/14, 1/21, and 1/53, respectively (Figure 6). This led to a greater recurve radius making the roof appeared more curved. The curves for the reinforced concrete roof of the National Central Museum were neither borrowed explicitly from any architectural elements in the Liao and Song dynasties investigated by Liang, nor did they completely follow the standards laid out in Yingzao Fashi (Figure 7). Therefore, it looked lighter and more extended than the traditional forms made of wood, a testimony to Liang’s recognition of the curved beauty of Chinese architecture.

Figure 5. The facade design of the main hall of the National Central Museum (Source: Lai Delin. (2007) Studies in Modern Chinese Architectural History. Tsinghua University Press, Beijing. page 334)

Figure 6. The design of the roof curve of the main hall of the National Central Museum

Figure 7. ‘juzhe’ method of building roof in Yingzao Fashi
2.4. Roof curve in the work of Tingbao Yang

After returning to China from his studies abroad, Tingbao Yang served as an architect in Kwan, Chu and Yang Architects & Engineers of Tianjin, which designed and built numerous excellent works. Among them, the building for the Research Institute of History and Language of the Central Academy, was designed by Yang and constructed by Liuhe Constructing Company, which located on the eastern foot of Jilong Mountain. The institute building imitated the palatial architecture of the Ming and Qing dynasties. It is a 3-storey reinforced concrete structure and a total building area of 1700 square meters. The plan is a rectangle, and it has gable-on-hip roofs with single, flat and straight eaves. The main roofing is not conspicuously upturned, only does the eaves, and is covered with green glazed tiles. The façade is in the typical three-level style of western architecture, including a podium, orders, and a roof, with balanced size and rational proportions. A long vertical ridge runs along the entire roof at about 1/5th of the roofing height. The cornice of the gable-on-hip roof protrudes 1.6m out from the walls. The ‘qiangji’ has very small bending radius, which nearly presents a straight line, making the overall building appearance slightly rigid (Figure 8). The building contains the elements of Chinese-style forms with certain changes. The south facade of the roof is concise and integrated, and a chimney and dormer windows are installed on the north facade (Figure 9). This shows the architect was positively exploring the design skill of combining Chinese and Western architecture, and trying to make the architecture satisfy functional requirements.

3. Study on roof structure

In order to learn how the architect gain the roofs curving, we should look the inside of roof trusses and to see why the western roof structure can be shaped in Chinese traditional roof profile. Since the architects made the roofs in different methods, the material should be varied as well.

3.1. Roof structure of No. 100 buildings in Gingling College

The roof of No. 100 building in the central part is a traditional gable-on-hip roof. The two stories in the middle were to be used as an indoor stadium, requiring a high interior space, which naturally led to an open roof arrangement. The open part of the roof is supported by a Howe truss, increasing the size of materials and appearing tidy and clean with no diagonal bracing between roof trusses. The roof truss has the span of 13m, a height of 4.6m, and a slope of 0.7. The top chord, bottom chord, and web members of each roof truss are all made of wood, the vertical members are round steel, and the connection clamp plates are either steel or wooden plates. The cross section of top and bottom chords (L×H) is
320mm×270mm, while that of web member is 180mm×160mm, with the vertical members and chord members anchored by bolts. This roof truss is divided into 4 sections transversely with each section spanning 4m. A total of 8 purlins are arranged on the roof truss, all of which are square timber of 190mm×190mm resting on wooden cleats. The purlins and rafters of the roof truss are covered with paved plank sheathing, which in turn is covered with paved tiles. The raising and depressing of the roof occurs in two parts, composed of two broken lines. The broken section, is located at the junction of the facade of the wall and roof, unlike the continuous curves of traditional Chinese roof. The angles of the broken lines are 35° and 30° from top to bottom, respectively (Figure 10). The roofing is flat and straight with no contra-flexure, and only a part of cornice is upturned. This indicates that Murphy did not understand the formation principle of Chinese curved roof, and did not seek proper methods to solve the problems related to curve design, thereby leaving him with no choice but to use the upturned roof cornice to poorly imitate the roofing of traditional Chinese architecture.

3.2. Roof structures of Regional Seminary of Kaifeng and Seminary of the Disciples of the Lord
The section profile for the chapel of Regional Seminary of Kaifeng offers an insight into obtaining a continuous curve of the roof. The Western saddle roof method was used for the main internal roof truss structure. The equilateral triangle wooden Howe truss was chosen to present the ‘juzhe’ method of Chinese architecture. Wedge blocks of various sizes were placed on the triangle hypotenuse from bottom to top. These wedge blocks were used to adjust the radius of roof curve. The purlins were placed on these wedge blocks, and ridge purlins were placed on short columns additionally extending upward at the top of the triangular frame, forming a steeper roof slope near the ridge. Finally, tiles were paved in accordance with the practice for the roof of Chinese architecture. The angles at the broken lines on the roof were 45°, 40°, and 28° from top to bottom, respectively (Figure 2). Three broken lines formed a continuous roof curve, indicating that Gresnigt had learned that Chinese traditional roofing was a continuous curve from the ridge to the eaves. The pitched roof of The Seminary of the Disciples of the Lord was a reinforced concrete structure. The roof with broken lines was directly made of reinforced concrete. There were three broken lines on the roof. The angles at the broken lines were 43°, 28° and 21° from top to bottom, respectively (Figure 4). The roof truss was in the form of a Fink truss imitated by reinforced concrete. Materials with different thickness were paved on the roof to make a smooth roof curve, and then roofing tiles were laid on the top. This approach not only shortened the construction period, but also was simpler than remaking the roof curve on the wooden roof truss structure. New building materials such as reinforced concrete replaced the traditional brick and wood materials, enhancing the durability of buildings.

3.3. Roof structure of the main hall in the National Central Museum
The roof of the main hall of the National Central Museum is a hip roof, which is supported by a steel
truss inside. The roof structure is a steel Howe truss with a relatively smooth roof curve (Figure 11). The building had a large internal span which required changing the top chord of the triangle roof truss from a straight line to a concave broken line, so as to form a smooth roof curve. However, this approach violated the principles of mechanics of the truss structure. The method that conforms to the rationality of structural mechanics is to instead modify the top chord into a convex broken line or a straight line. The structural stress considerations therefore dictated that instead of supporting the entire roof span by a Howe truss, the load could be divided between a Howe truss and a reinforced concrete structure in such a way that roughly two-thirds of the span was supported by the Howe truss with the rest one-third being supported by the reinforced concrete structure. On the one hand, this approach reduced the size of roof truss materials and saved materials. On the other hand, considering the function, the middle part of the span was granted a lofty space, while a narrow space was formed at both ends of the span. This approach was at the time an innovation in structural design, improving the utilization rate of roof space to a certain extent.

3.4. Roof structure of the Research Institute of History and Language of the Central Academy in Nanjing

The roof structure of the Research Institute of History and Language of the Central Academy in Nanjing employed a Fink truss in combination with a reinforced concrete frame structure. The upper part of the roof presented straight line, and the bottom was relatively smooth. There were three broken lines in the locations of gold purlin, ridge purlin, and eave purlin. Section ‘ab’ was about 3 times longer than Section ‘bc’ with the lengths of sections ‘bc’ and ‘cd’ being roughly the same (Figure 9). The angles at broken lines were 40°, 20°, and 10° from top to bottom, respectively. The method adopted for forming the roof curve was to fix the gold purlin directly to the top chord of the roof truss, and raise the ridge and eave purlins correspondingly, so that the end of ridge purlin was higher than the apex of the triangular roof truss. Eave purlin was placed on top of a short column with an appropriate height lifted by the top chord of the roof truss. In this way, the line connecting the three purlins was a broken line, thus giving the roof curve a traditional Chinese architectural appearance, and indicating a profound understanding of Chinese traditional architecture by Chinese local architects.

4. Conclusions

In the numerous traditional revival buildings in modern China, both Chinese and Western architects seem to be focused on the problem of the appropriate modification of Western roof truss structure in order to obtain a roof curve with the celebrated Chinese ‘raising and depressing’ effect, while simultaneously satisfying the functional requirements of large space. The present investigation has found three common approaches in specific design practice:

1) When the roof truss has a smaller span (generally within 20 m), triangular wood roof truss is used to raise the ridge, eave, and cornice purlins in the following manner: The ridge purlin is raised by extended the upper end of column at top of the triangular roof truss. Raising the eave purlin is achieved by placing it on the eave wall and selecting appropriate height as requirement. The cornice purlin is raised either by placing it above an overhanging bracket set at the cornice or the beam head, or by adjusting the height to an appropriate value. The gold purlin is directly fixed on the top chord of roof truss with the height unchanged. The connecting line of all the purlins is therefore a broken line. An example of this type is the No. 100 building of Gingling College.

2) When the roof truss has a smaller span (generally within 20 m), on the top chord of the equilateral triangle of the roof truss, wedges with different heights are laid according to curved line. The purlins are then laid over the top chord so that the line connecting the purlins is a broken line. An example of this type is the Regional Seminary of Kaifeng.

3) If the roof truss has a larger span, the upper chord of the triangular roof truss is changed from a straight line to a concave line according to the horizontal spacing between purlins. Alternatively, a more elaborate curve may be directly shaped from the broken line by reinforced concrete. Examples of this approach are the Seminary of the Disciples of the Lord and the National Central Museum in Nanjing.
After the above approaches are implemented, the roof structure is processed, and the material thickness is adjusted in the construction, forming a natural and smooth roof curve. Different architects show distinctive design features for roof curves. It appears that Murphy did not fully understand the contrary flexure mode of Chinese-style architecture roof, but used the upturned surface at the cornice of the roofing to imitate the curve of traditional Chinese roof. Consequently, the angles of inclined planes for the roof designed by him are 35° and 30°, which are less than that of Chinese traditional roof. The angle at the broken line of the roofing designed by Gresnigt is larger, and the roofing is more curved. Liang, however, followed the ‘juzhe’ method in Yingzao Fashi to make the roofing gently stretched. Yang used the broken lines to form the roof curves resembling those of the traditional Chinese architecture. The slope near the roof ridge in the works of the last three architects was about 43°, which was closer to that of the traditional roofing. In the process of exploring Chinese traditional revival architecture, it appears that both Chinese and Western architects as well as engineers had to be creative to provide architectural solutions suitable for the construction technology conditions of the times. Their explorations towards combining the architectural elements from two distinct styles have contributed greatly to the modern transformation process of Chinese architecture.

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References
[1] Lai, D. (2007) Research on the History of Modern Chinese Architecture. Tsinghua University Press, Beijing.
[2] Lai, D. (2016) Modern Chinese Architecture History and History of Architecture History. China Architecture & Building Press, Beijing.
[3] Li, H. (2004) Modern transformation of Chinese architecture. Southeast University Press, Nanjing.
[4] Dong, L. (2010) Research on the Architectural History of Modern Chinese Christian Universities. Science Press, Beijing.
[5] Liu, Yi. (2006) Outstanding contemporary Chinese architect and architectural educator: Tingbao Yang. China Architecture & Building Press, Beijing.
[6] Ghesquière S.J. (1941) “Comment bâtirons nous en Chine demain ?”[J]. Collectanea commissionis synodalis, 14, Beijing.
[7] Luo, W. (2018) A Preliminary Study of Western Architects' Localization of Architecture in China—Gleason's Practice in China (1927-1932). In: Chongqing University Press. pp. 71-76.
[8] Dong, L. (2004) An Review of the Establishing Process and Architectural Art of Gingling college. Journal of South China University of Technology (Social Science Edition), 06: 57-61.
[9] Lu, C. (2018). The Research on Campus Plan and Architecture of Gingling College Site. Master Thesis, Southeast University.
[10] Liang, S. and Fairbank, W. (2005). Chinese Architecture: A Pictorial History. Dover Publications, New York.