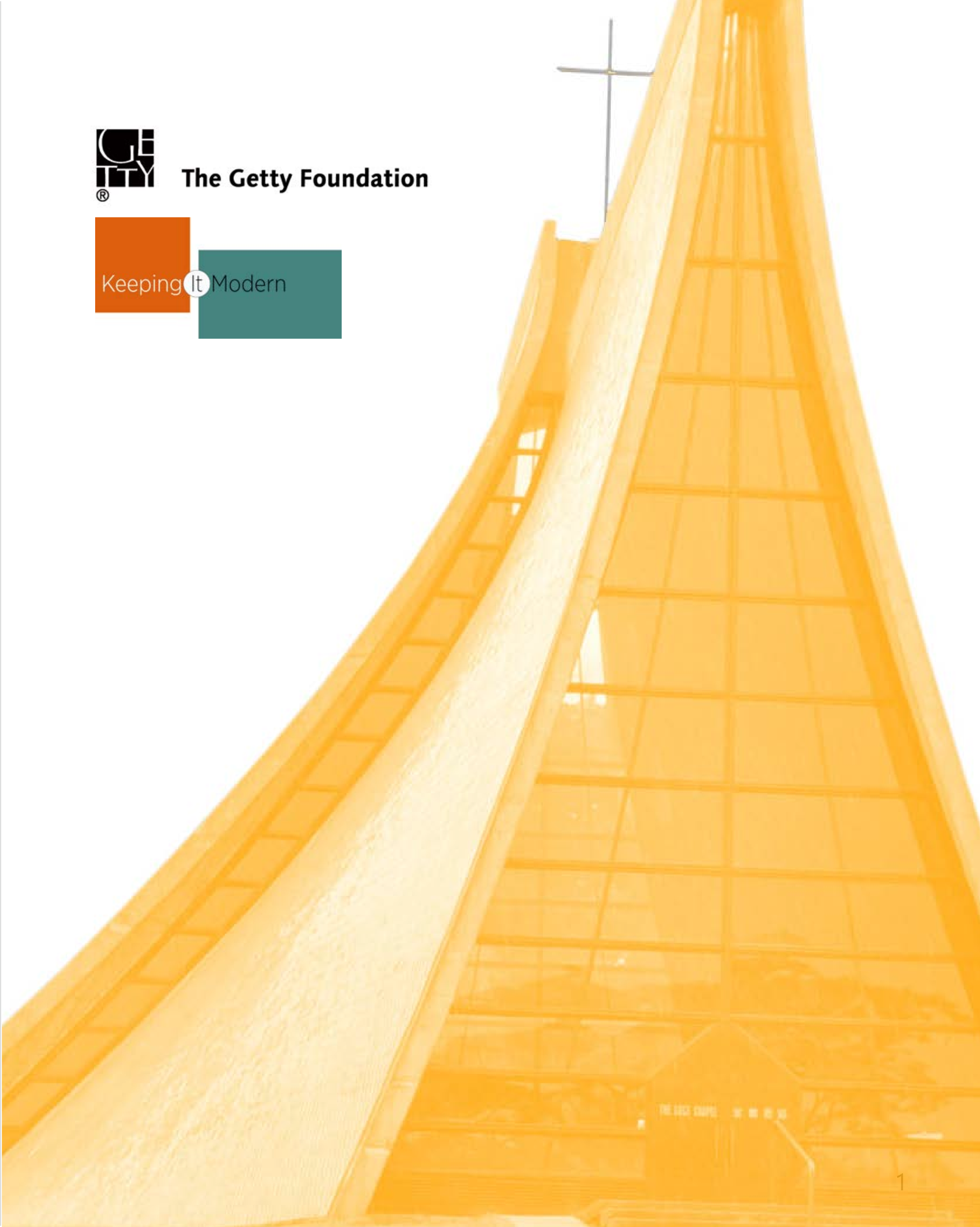
The Getty Foundation

Keeping It Modern



Preface

Luce Chapel is a renowned architecture in Taiwan. With its outstanding achievements, it certainly stands outin the modern architectural movement of post-war Taiwan. In October 2014, Luce Chapel was chosen to be one of the ten global classic modern architectures, and the first project within Asian architecture,which received the first "Keeping It Modern" (hereafter abbreviated as KIM) Grant from the Getty Foundation. The Grant acknowledgesthese 20th century modern architectures as milestones of human civilization. With high experimental mentalities, groups of architects and engineersof the previous centuryboldlytried out exploratory materials and cutting edge construction techniques, and built innovative architectures thathave stimulated changes in their surrounding environments, histories, local culture, and forever transformed the philosophical approaches of architecture. However, the Getty Foundation also regards these architectures to be under various degrees of risks. Being fifty to sixty or even older, many of these innovative materials and techniques boldly used at the time oftheirsconstruction were not, and still have not been scientifically tested and analyzed to this very day. Furthermore, the productions of many of these materials have been discontinued due to low adoptions in the market, making conservations even more difficult. Therefore, the Getty Foundation KIM grants promote the sustainable conservation of modern architecture. This focus has also been the core value of the Luce Chapel conservation project.

Built in 1963, Luce Chapel has stood on the campus of Tunghai University for over 50 years. This building was designed and built to function as a church building, and has maintained its religious purpose over the years.However, as the number of faculty and students continues to grow,the space demand for community engagements and ceremonial activities of colleges and departments on campus have also increased extensively. Besides being a place for Christian worship, the chapel has also been an important venue for alumni and faculty to hold weddings and some memorial services, and is nowopen for performances of important artists and performing groups, school's opening and closing ceremonies, and graduation commencements. Due to its frequent usage and swelling demands on supplementaryfunctions, the school also needs to reinforce the chapel's sound system, lighting, air conditioning apart from replacing, renewing and maintaining worn materials and deteriorated construction modules. Every restoration construction would inevitably alter the body of the chapel to a certain degree. Some operations can even cause unintentional and irreversible damages. Therefore, this research project is divided into "Historical Background Research," "Investigation and Repair Strategies forMaterial Damages," and "Functional Upgrades." The discussion on "Historical Background" includes two major topics. First, we shall discuss the evangelical purpose of Luce Chapel under its historical context as a church building in a Christian university. Accordingly, we will review its purpose to serve as "a testimony for missionary works," "a university chapel," "a modern architecture in an Asian Christian university," and "a testimony as contemporary cultural encountering between the East and the West." From there, we shall mark the historical significance of the conservation of Luce Chapel, and explain how the Luce Foundation, United Board for Christian Education in

Asia,and Tunghai University gladly came to agree on the style of thisparticular built form. The research shall also use this as a foundation to reviewthe interview records with the main designer, Chi Kwan Chen, and the photos and construction documents accumulated at the time of its construction. Through scrutinizing these records, we are trying to track the entire design process of the chapel besides illustrating detail architectural techniques, such as model testing, structural decision-making, site planning, and environmental planning. Studies on the later historical topic is meant to help the research members involved in the sub-projects of "Investigation and Repair Strategies of Material Damages" and "Functional Upgrades" to tie their research on the "authenticity" of the chapel, and make the repair principles based on historical restoration.

Sitting on the campus of Tunghai University,the repairment and maintenance of Luce Chapel had long been a work of collaboration between the Tunghai University Christian Church and the school's General Affairs Officefor over fifty years. Therefore, the Architecture Research Center has worked jointly with the office of General Affairs on the"Investigation and Repair Strategy of Material damages." Through retrieving the original blueprints, construction contracts, construction photo records, and available repair records from the office of General Affairs, the Architecture Research Center is able to compare with the on-site records and make attempts in restoring the original condition of the chapel uponcompletion in 1963, and its actual conditions in different repair stages after the mid 80s. Along with the interview records with Chi Kwan Chen, historical and professional analyses toward Luce Chapel accumulated within the curriculums of the Architecture Department over time, the sub-project teams have a firm base for their studies on"Investigation and Repair Strategies of Material Damages," and "Functional Upgrades."

Therefore, this project further breaks the topic "Investigation and Repair Strategies of Material Damages"into the following four categories: "structure" (Structural Investigation about Seismic Simulation of Henry Luce Memorial Chapel), "construction" (Construction Investigation, Conservation and Restoration of Henry Luce Memorial Chapel: on Tiles, Foundation, Mortar, and Openings), "wooden objects" (Research on the Conservation Methods of Wooden Objects in the Luce Chapel), and"tiles and glaze" (Investigation and Discussion on the Conservation of Tiles of the Luce Chapel). In the category of "Functional Upgrades," the topic is further diverged into four sub-categories: "improvements and restoration project on the thermal environment (The Research on Luce Chapel Conservation---The Investigation and Improvement Plan of Thermal Environment), "air conditioning installation project" (Luce Chapel HVAC System Renovation Study), "improvement project on the acoustic environment" (Acoustic Diagnostics and Suggestions Regarding the Luce Chapel), "studies on the lighting environment and lighting improvement (The Lighting Plan of Luce Chapel, When It Was Constructed). Besides project members who are in charge of the above research topics, Tunghai University Christian Church is also asked to deliver a utilization plan of the chapel as a foundational reference for functional upgrades.

Surely, the architectural value of Luce Chapel is beyond doubt. After being chosen to be one of the first research objects to receive the KIM grant from the Getty Foundation, its significance as a cultural heritage has been further established. Before it was granted, the administration departments of Tunghai University have also applied forthe desiginationof Luce Chapel as a cultural heritage. In one of the school's administration meeting, it was agreed that the building should be valued as a "national monument," the highest level of national cultural heritage, and a promotion for designation by the Minister of Culture of the central government of Taiwan had beenenacting accordingly.

When the construction of Luce Chapel began in 1962, there were noarchitectural regulations, nor restrictions on hillside exploitation at Taiwan. Therefore, no architectural license was verified before the construction. Today, demands for fire control, emergency exits, and barrier free environment have grown. Neverthelessthese issues were resolved through "corresponding regulations" under the principle of honoring the original look of the chapel upon recognition of its identity as a cultural heritage. Thus, issues on improving fire control and barrier free environment are not included in this project.

This project began in October 2014, and was carried out to the end of February 2016. Since the application on the desiginationof Luce Chapel as a cultural heritage was not yet approved by the end of this project in 2015, this research project was not able to be put together cohesively and published as a thorough repair guidebook. However, the execution of this project still held on to the goal of the grant, which is to accomplish a scientific detail analysis on the innovative materials, construction methods, structural systems of Luce Chapel, a classic piece of Asian Modernism.

Once Luce Chapel is listed as a cultural heritage, the repair principles for the restoration sub-projects shall function as a credible reference for professionals to make practical restoration plansin accordance with the Cultural Heritage Preservation Act. It is also a useful reference forthe publications regarding the conservation of the chapel. This project shall also provide conservation standards with analytical data on acoustic improvement, air conditioning refinement, and lighting plan, etc. for members in charge of cultural heritage preservation to use as a basic reference to establish restoration criteria. Preservation of tiles and glaze is more difficult when considering the constraints on the terms and conditions required for low-temperature kilns, and the debates on whether to preserve the "original body" of relative objects. There are also some issues on technical problems of restoring principals yet need to be discussed. Beforefirm decisions on the conservation principles are made, restoration projects on tiles and glaze shall focus on preserving and recycling the glazed tiles. We are very grateful for the help of Getty Foundation. Through the conservation research on Luce Chapel, preservation of modern architectures in Taiwan has finally come to light. The aim of this grant has revealed a way to view modern architecture subtly and rationally, which surpasses the traditional studies on forms and styles. With the conservation research project of Luce Chapel, we hope this should further initiate movements for preservations of modern architectures in Taiwan. May this be a pivotal reference for future modern architecture preservation projects, and activate another preservation action of modern architecture.

Relocating Luce Chapel—

its cultural significance through the encounters between East and West

by Kuo, Chi-Jeng (professor, Dept. of Architecture, Tunghai University)

Preface

As a renown classic modern architecture in Taiwan, the Luce Chapel stands as a remarkable testimony for the far-reaching influence of western Modern Movement in the 50s. The celebration of modernism had made a marvelous presentation through thearchitectural concepts and techniques adopted on the chapel. They included :the four individual concrete curved walls made to experimented parabolic hyperboloid concept, the interior space beneth the four curved walls along with the structural details made for not only enacting the buoyancy-ventilation effect when air conditions were not yet popularized, but also for a great indoor acoustic space with amazing reverberateon for musical performances, etc. Besides, thegeometric pattern on its plan layout, lattice beam anddiamond-shaped tiles on the exterior RC wall unifies the plan, façade and section of the architecture, and reflects the contruction team's proficiency on geometric structure. This is also an practical demonstration of modern rationalism in terms of architectural logic and structure. In this chapter, the discussion will take a detour from the chapel's achievement as a modern architecture, which has already been widely recognized and discussed, and dig in on the historical and cultural aspects of the chapel. We shall delve into the less told stories, and see if the significance of these cultural and historical stories provide a different point of view to Taiwan's or even Asia's architectural movements of the era, and have it serves as a reference for new alternative theories for regional artchitectural history.Meanwhile, we shallfirst reveal the historical and cultural significance of the chapel through tracing the mission journey of Henry Robinson Luce in Asia, the very root of this memorial chapel,then discuss the architecture as a campus chapel, and its importance as a modern architecture. In the end, we shall close the chapter bydefining the historical and cultural significance of the existence and conservation of Luce Chapel under the historical context of the East-West encounter in contemporary Central Asia.

1. A testimony to the Protestant Christian Mission History in Asia

The building of Luce Chapel was sponsored by Mr. Henry R. Luce(Luce Jr, the founder of "Time" and "Life" Magazine), in loving memory of his father, Mr. Henry W. Luce (LuceSr) for his devotions in evangelism. After Graduating from Yale University in 1892, Henry W. Lucefirst spent 2 years in Union Seminary and then another 2 years in Princeton Theological Seminary for his mission trainings before being ordained by the Presbytereian Board of Foreign Missions in 1897, In the same year, he decided to join the mission fieldin China, and devoted himself to the work for 31 years before moving back to the States in 1928.

The mission trace of Luce Sr. in China is not simply a personal mission journey, but a glance of the mission works of western Chrisitan communities in China. Ever since Robert Morrison went to China in the late Qing Dynasty, Protestant churches of the West have continued to send missionaries through various missionary societies for the purpose of evangelism. After mid 19th century, these communities even established bases in some settlements under the protection of Unequal Treaty for the development of mission works in inland provinces. However, withthe Chinese resentments toward the "foreign religion" and growing sense of

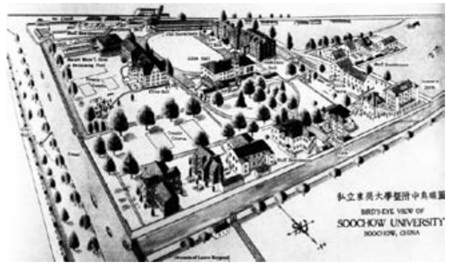
nationalism, which flourished under the oppression of colonialism, resistence such "Anti-Christian Cases," and "Christian Independent Movement" began to thrive. The Christian communities was then forced to ponder over thenational conditions of China as they began their ministries in China. At the time, extreme nationalism had corrupted the minds and bodies of many indigenous Chinese, and people started to embrace intectuals' call for "reformation," which proposes an education reform with "Chinese learning as fundamental principles and western learning as practical uses." Anti-imperialism movements led by Liang, Chi-Chao, Kang, You-Wei, and Sun, Yat-Sen, saught to overthrow the old regime of the Qing Dynasty. Under the circumstances, Christian communities had to both adapt to a feudalism culture and meet up to the intellectuals' expectation by providing "advanced ideas." Therefore,in order to meet these public expectations in China, ministries such as schools and new industries began to bloom as means of evangelism among missionary communities. In these ministries,Christian universities blossomed as the main evangelical medium of the era. Luce Sr. was one of those missionaries who witnessed the trend of using Christian universities as the bases and outposts for evangelical activities in China, and the maturing of its development in 1880s. Founded in the Shanghai International Settlement, St. John's University became China's first Christian university in 1879. Later, church universities such as, Jinling University(Nanjing, 1888), Lingnang University(Guangzhou, 1888), Hangchow University(Hangchow, 1897), Soochow University(Soochow, 1900), Aurora University(Shanghai French Concession, 1903), Cheeloo University(Jinan, 1904), Peking Union Medical College(Beijing, 1906), West China Union University(Chendu, 1910), Shanghai University(Shanghai 1911), Hsiang-Ya School of Medicine(Changsha, 1914), Jinling Women's College(Nanjing, 1915), Fujian Union University(Fuzhou, 1916), The Woman's College Of South China(Fuzhou, 1915), YenchingUniveristy(Beijing, 1919), and Fu Jen Catholic University(Beijing, 1925) rised and thrived. After being in China for 7 years, Luce Sr. joined the ministry of Cheeloo University, then went on to assistYenjing University in 1917. He was deeply involved in the establishment and fund raising of these two univerisities. Although the aforementioned universities were established by mission communities of different denominations between 1880 to 1920,novel education systems, ideas, and curricula were common practices. This was the era when the traditional Chinese imperial examination system which had prevailed in China for more han 1300 years was abolished; therefore, western academic programs took place just in time of to fill in the educational gap and provided great demonstrations and guidelines for contemporary education in China.

When the Second Sino-Japanese War ended in May 1945, 13 out of the aforementioned universities went under the management of the United Board for Christian Higher Education in China, whoseestablishment could be traced back in 1910s with New York as its base to coordinate issues regarding the finance and overall developments of these Christian universities. This board later became the "United Board for Christian Education in Asia"(hereafter referred as "the UnitedBoard")[1], the same board founded Tunghai University in Taiwan, and activated the buildining project of the Luce Chapel.As a memorial site for Luce Sr., the Luce Chapel also stands as a symbol for the evangelical history in China whichLuce Sr. took part, witnessing the intimate connection between Christian mission history and western Modern Movements within the Chinese society.

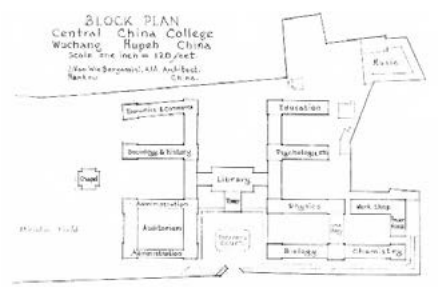
2.As a Campus Chapel

For non-Christian countries, having a religious architecture such a chapel on campus is highly unlikely; placing one at the center of a campus is next to impossible. Erected at the center of a Christian university sponsored by the

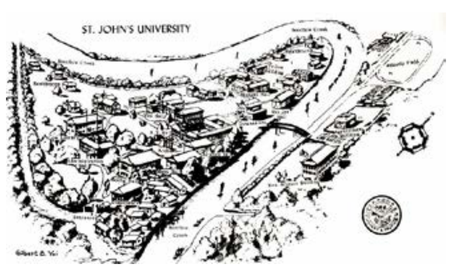
1.Most people recognize the "United Board" as an organization which founded numerous Christian universities in China. According to the board's archive currently stored within Yale, it took a long journey for the board to be finally "united." Its history can be traced back to the May 4th Movement in 1919, a time in which nationalism in China was thriving. The call for national universities and the apparent trend of higher education reform in China were the key that brought these mission communities together, and became one "unified organization" to make sure the mission work in China stayed effective. However, the "coalition" of Christian universities across northern and southern China had been a long quest. It had always been reasonable but executionally difficult for the coalition to take place. It was not until the Second Sino-Japanese War which forced the schools to make temporary alliance through sharing academic space, curricula, and teachers. Postwar alliance continues through the "massive donating promise" from the States, which initiated the opportunity and discussion on the "coalition" within the board. Nevertheless, actual coalition did not take place until the Republic government retreated to Taiwan, following the communist government's restriction on the mission works of church universities. (Liu, Jia-Feng (2003) , Wei Jing Z. M: Hua Dong Lien He Da Xue Shi Mo [A Dream that did not come true: the history of East China United University], Ji du jiaoyuzhongguo she hui wen hua: di yijieguo ji nianqingxuezheyantao hui lun wen ji, 1-2, 4-6.


Soochow University

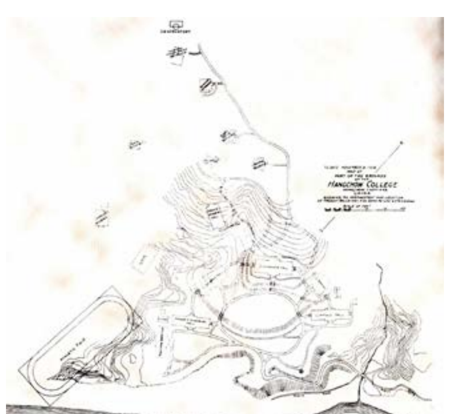

Shanghai University



Huachung University

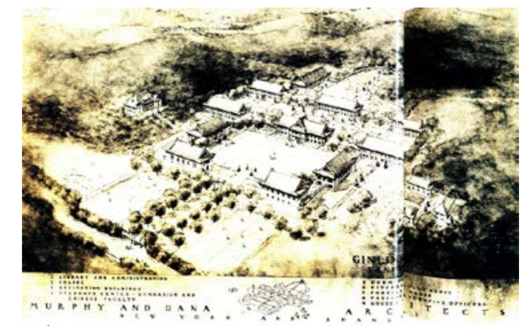


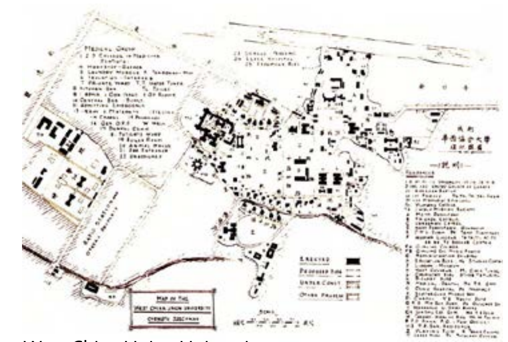
St. John's University

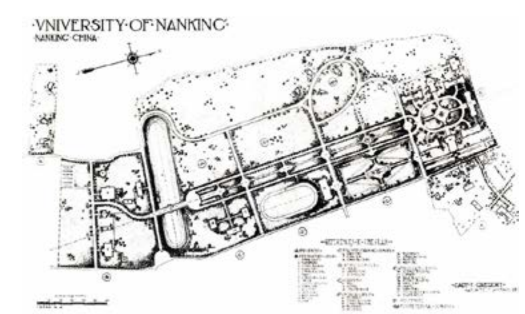

Hangchow University

United Board, theLuce Chapel does not simply stand as a church on the campus of Tunghai,but also an unique demonstration for the founding spirit ofthe university'seducational ideals and implication of its campus layout plan.
As aforementioned, when Christian missionaries arrived in China in early 19th century, they came up against the nation's stern politicial condition. Therefore, when various demoninations chose schooling as the stepping stone for envangelismamong the Chinese, they first encountered the problem of "how o adapt themselves to China's nationalism condition?" Usuallymost founders consciously adopted "Chineselocal style"architectures instead of using entirely western style buildings to win over local acceptance.This was done through partially or fully adopting traditional Chinese architectural structures or adding some Chinese construction detail elements. The design of these campus buildings oftenreadjusted the structural spans, ceiling heights,and attachedtraditional Chinese roofs such as tile roof, curved roof, roof ridge, flush gable roof or overhanging gable roof on the main concrete structure, a techniquegradually gainingpublic favors at theera. This type of new architectural style appeared around late 19th century to early 20th century. The style of these buildings stands as a witness to the intimate connection between missionaries, the higher educational system they brought into China, and the westernization and modernization of Chinese architecture.
Therefore, in order to inspect the significance of Luce Chapel as a campus chapel regarding its architectural form and its position in the campus layout, we must do so under the context of the history of China's church universities. If we set aside the 13 universities sponsoredby the United Board for inspection, two major patterns can be observed:
In the first type of pattern, the campus spaces appear to be random and organic, with no explicit geometrical patterns found in the campus layouts. When a campus layout lacks clear axes or geometric structures, this usually means that the entire campus environment was developed through a long period of time. This type of campus pattern was mostly found in the schools opened before the May 4th Movement, when nationalism was not yet matured.With limited financial resource and manpower, most missionary communitieswould choose to set up offices and places for worship first, as they continuedto raise funds to expand school land and buildings. This includes St. John's University(1879), which was China's first Christian universityestablished in the Shanghai settlement. Following the establishment St. John's, Shanghai University(1911), Hangchow University(1897), Soochow University(1900), Huachung University in Wuhan(previously known as College of Yale-in-China, 1906,), and Fukien Christian University(1916) were founded. Among these schools, there are those unable to develop a geometric campus layout for being on top of hillside fields, e.g., Fukien Christian University and Hangchow University, and those bound to organic layout patterns due to the size limit of the land, e.g., St. John's University, Soochow University, Shanghai andHuachung University.
The second type of campus pattern is mostly found in schools opened after mid 1910s. This was the time when the power ofmissionarycommunities or denominations were brought together from various regions. With invovlements coming from different organizations in the States, fund-raising thus required clear campus layout plans. These Schools no longer had to develop their campus from small parcel of land and care for land-use efficiency. Instead, collective fund-raising had those new universities comparactively sufficient budget for campus planning. Those schools often had plenty of land, and the concern of land size became the smallest trifle, leaving enough room for well-developed, comprehensive campus layout plans. Among this type of campus, there are those with full sets

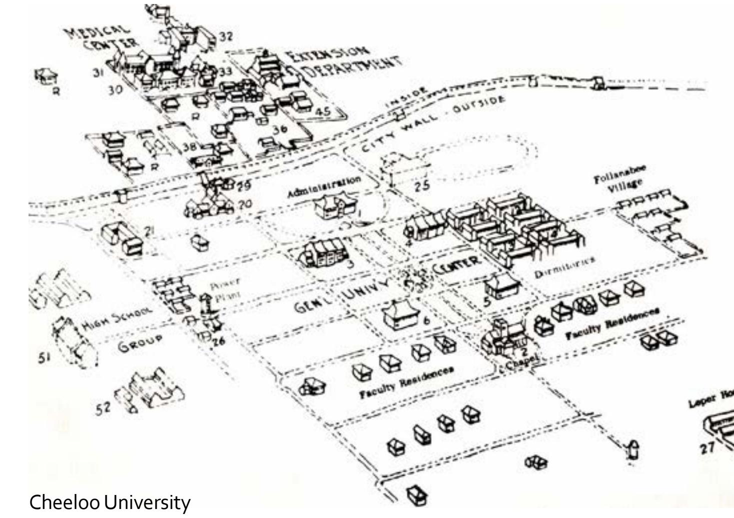
Yenjing University


Jinling Women's University

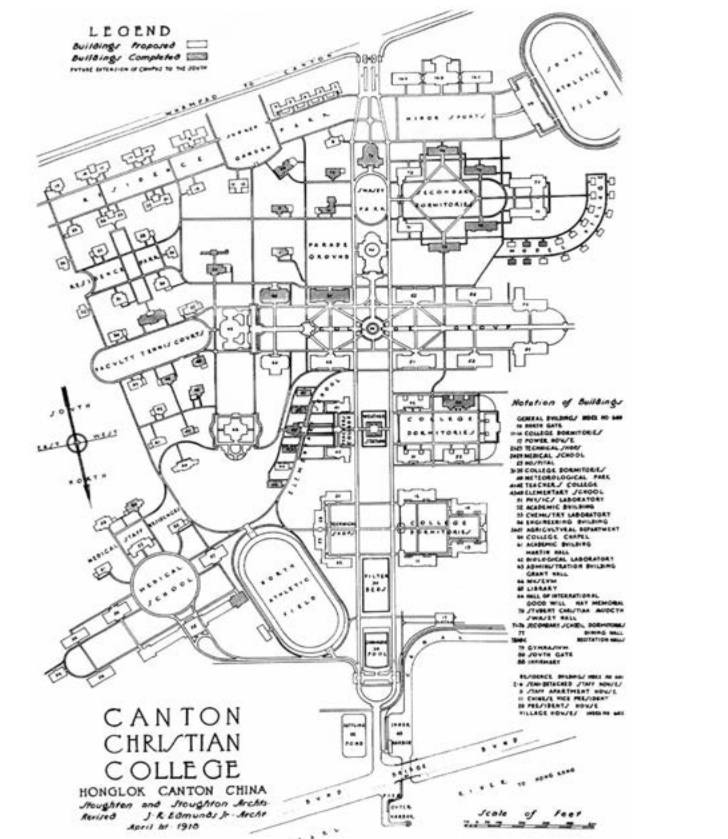

West China Union University



Jinling University



Cheeloo University



Lingnan University

of compound structures, e.g., Yenjing University(1921), Jinling Women's College(1916), and West China Union University, and those with explicit axes which dominate the spatialarrangement of the entire campus, e.g., Cheeloo(1917), Jinling(1928), and Lingnan University(1928).[2] ;
In the aforementioned church universities, whena chapel was included in the original campus design would determine itslocation and form.For universities with relatively organic layout and non-specific geometric spatial

2.Cheeloo, Jinling, and Lingnan University all had their forerunners. Their overall layout plans took place when their missionary communities joined to form a united committee, and handed over the campus designs to particulararchitects. The written timeline is recorded according to the year in which the missionary communities entrusted the campus design to Henry Murphy and his united firm,Murphy, McGill & Hamlin, or the year when the construction of the school's first campus building took place.

The interior of the chapel within Huazhong University

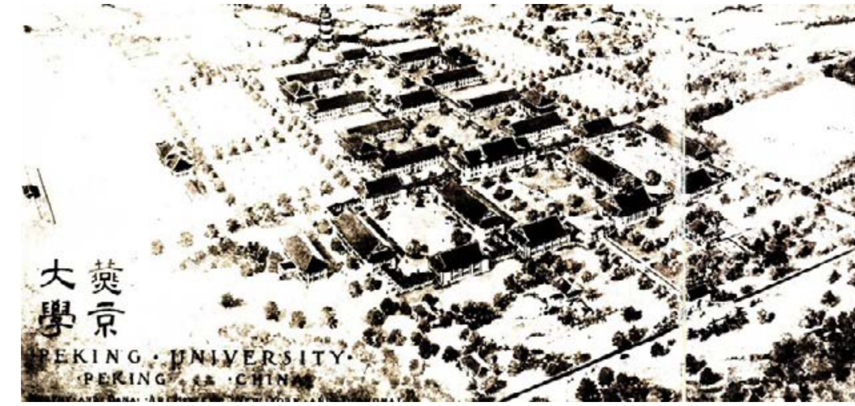
structure, e.g., Soochow University, Hangchow University, Shanghai University, and St. John's University, chapelswere neitherincluded in specific geometric structures, nor clustered with other school buildings. These chapels often came before the establishment of school buildings, with missionary communities longing for a place to worship at the initialfoundingstage of the universities. The chapels were usually built soon after the school property was bought, and generally freedom consists in their forms and randomness in locations—they are either close to the gates, next to the initial location of the main school building, the administration centers, or on the highest spot of the school property as a symbol of devine sovereignty. Take Hangchow University for example, originally, it wasn't necessary for the schoolbuildings to be spread across the fields next to Qiantang River. Even though the Tooker Memorial Chapel does not stand on the top of the hill, it is still erected high above all other campus buildings. Without the intension to unify its style under nationalism, not the slightest hint of Chinese architectural pattern is found. The chapel within Huazhong University shares the same issue concerning its land. Limited by the terrain and size of the land, the founders still strived to demonstrate the importance of the chapel to the school. The campus buildings of Huazhong University can be seen as onebuilding with multiple wings, which are jointed, forming a smallcompound. The tower by the main gate later became thelibrary. The high tower and the library within stands as a direct implication of the school's academic spirit. On the other hand, the chapel lays on the west end of the campus, and is separated from the jointed compound structure, standing quietly by itself. Its architectural style also stands out from other campus bulidngs withinHuazhong. Small-scalecolonnades anda lower gateway are attached to its exterior, and its architecture is apparently more solid in terms of mass. In comparison to the tall library erected by the gate, the chapel sits at the corner of the campus as an clear illustration of the school's public image and its internal identity.

Even though the school land is limited in size, the founders of Huazhong still made the effort to createa quiet place for worship. Besides being a place for Christian worships, this individual corner also allows Christians to have fellowship with those who share the same religious identity.

When land is strictly limited, inevitably some chapels would have to share its building with classrooms or administrative offices. The chapel of Shanghai University is one of these examples. It's a two-storeys western style building with the worship services held on the second floor while the first floor is used as the church's office area. The position of the chapel lies at the intersection of two pathways connected to faculty, staff, and student dormitories and classroom buildings.Thisposition and thebuilt form of its religious worship space silently declares the religious identity of a church university. Built also with a limited land space, Soochow University, originally a junior high school, does not have a chapel on campus due to a church preexisted right across its campus. This example stands out as an exceptional case for the religious practice arrangements of Christian universities in China.

However, Christian mission communities to which the aforementioned universities are subordinated, did not come to an agreement on these chapels'"freedom" of their forms.Jeff Cody, an architectural historian specializes in contemporary Chinese architecture indicated that by late 19th century, after commercial activities in China became ever more opened, some people started to question whether it was necessary for their buildings(in China) to have a European appearance. Perhaps this was because some foreigners no longer minded to work in a Chinese building by the 1860s with their positive experiences in certain buildings[3]. Once these foreigners began to adapt to the unfamiliar spatial forms in China, the question of"how to adapt under the nationalismcondition of China?" remained. Mentioning

3.Cody, Jeff 2003 p.74



燕京大學（原規劃）
Yenjing University (Original Layout Proposal)

the discussion on architectural style, cultural aspects of considering emerged.

M. H. Throop, a Christian observer who went to China in 1924, gave a clear picture on how churches were built in China. He indicated that normally, if the local conditions met all the requirements, a church or chapel would be built following the exact same manner of certain church in America or Britain, bearing the same name. Throop was clearly against this type of "direct transplantation," especially when a church shows total ignorance towards its surrounding environment. He explained that beautiful or not, none of these churches blend in to the surrounding environment. Every city in China has its own unique architectural style, and it is apparently awkward and unfitting to implant a gothic church of the Victorian era. Throop's point of view is not prophetic to the later developments. When we took the architectural phenomenon which took place after the collapse of Qing Dynasty in 1911and made a parallel comparison, we found a grand Chinese roof attached directly to a British style brick building in the West China Union University, which started its enrollment in 1910, a decade before Throop's arrival in China. This was also way ahead the new nationalism movement which took place between the founding of the Republic (1911) and the May 4th Movement (1919). At that time, there was still an argument between "building the best western style architecture" and "trying something new (Chinese style)."[4] Later developments clearly shows the latter to have gained the upper hand. Cheeloo, St. John's, and Jinling University all "tried to blend in some traits of Chinese architecture to their design proposals." The Annual Report of the Board of Foreign Missions written in 1914 clearly shows that "a type of orientalized western architecture has been adopted. This type of architecture demonstrated the spirit of harmony and unity that exist throughout the entire communion, and its goal to unify East and West."[5]

This trend of development reflected on the policy of these church universities'campusbuildings, especially those with a full set of proposal for campus layout instead of random developments. In this catagory, the location and form of a chapel seem to adopt another set of principles. Firstly, for campus organized mainly under the geometric compound layouts, most missionary communities chose to continue the principle made for"adapting to the nationalism condition in China," an idea which started in late 19th century, and completely adopted local architectural styles to their campus buildings. From the original campus layouts of Yenjing and Jinling University, we can see the designs of these school buildings to be clearly following a similar principle. Instead of manifesting a church building in the overalllayout, chapels weremanaged as a subordinate body to the enclosed compound structure. These two universities were both designed by architect Henry Murphy, who believed all campus buildings should "be thought as one entire body, and designed as one complete unite."Thefore, in the discussionof campus buildings' style, the body of a church building should no longer be bound to the forms of traditional church of the West, but follow the same formation of all other campus buildings in a low profile.In other words, a chapelshould blend in so well that without an introduction stand,people shouldn't recognize the building to be a chapel at all. Instead of accentuating the religious identity or origin of a church university/college throughsymbolic forms, this arrangement would be regarded

4. Ibid. p.76
5. Annual Report of the Board of Foreign Missions, 1914 p.157

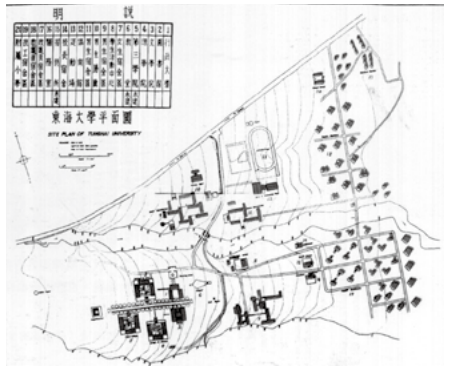
truly the ultimate way to "adapt to China's nationalismcondition!"
Other than simply adopting apparent geometric campus layout by applying the compound structure, some schools used a campus mall or central square as an "datum"to organize their campus buildings. For instance, universities such as Cheeloo, Beijing, Jinling, and Lingnan(the largest and most complete in terms of scale and formation),evidently started to boldly interweave compounds and axes to create spatial hierarchies. The most important campus buildings which the universities' founder proposed to have it distinguishable were often placed on the highest significant location on campus, or to be accentuated its uniqueness by its differentiated form or style. For example: universities built on a smaller scale such as Cheeloo University, its chapel, administrationoffice and four academic buildings were built around a central square, which is aligned to the north-south axis. The administrationbuilding and the chapel stand at the opposite ends of this linear-shaped central square. This type of formation clearly manifests the importance of a church building. Simliar arrangement also appears in Yenjing University. Like Cheeloo, it places the chapel at the most important and most eye-catching spot of an axis-aligned space. Unlike the original campus layout plan, the officialblueprint of Yenjing University has numbrous quadrangle houses which were used into the dorm, classroom, and administration areas. These quadrangle houses surround a huge lawn with the church in its center, like stars twinkling around the bright moon. This type of arrangement clearly indicates the dominance of the church in the campus layout. With similarsize land property, Jinling and Lingnan University have completely different layouts. Both campus are large enough to have an axis-aligned space that spreads hundreds of meters long. The lengthy axis becomes the focal points of the campus, and divides the space into different purposes.
With the largest land property, Lingnan University was able to have both an x and an y axis to organize its campus layout. They axis is a north-south axis that connects the access to the main roads on the north and south ends of the school. The length of the north-south axis is 3 times longer than the east-west axis,which aligns the belt zone of academic and administration centers. The faculty and staff dormitory lies at the north of the axis with the Christian Acitivity Center closing its north end, while the studentdormitory lies at the south overlooking the vast Zhujiang River. Instead of closing the south end with a building, a swimming pool with spectacular landscape, a church, and a semicircular plaza were arranged to create an visual extension to the inside campus view. The church stands at the intersection of the two axes, highlighting the importance of the building.
Founded in 1910, Jinling University set up a long axis accommodating to the aspect radio of its linear land property, and allocated the school buildings accordingly. Its chapel stands at the end of the axis as the visual closing. However, its boulevard does not lead straight to the chapel. From the layoutdiagram, a clear dotted line aligned to the axis extends to the west, and pointed towards the chapel in the west. The design deliberately withholds the significance of the chapel by setting it off the axis, and yet still subtly manifests its importance to the campus by accentuating its visual focal point. Once again, the thoughtfulness behind the design tells the countlessscruples of Christian missionarycommunities as they entered China.
Without having tofollow the compound layout structure, the chapels of these four universities contain a higher degree of freedom in terms ofarchitectural form. However, if we look deeper into the essence of these campuses' spatial formations, we will still find cultural measures and restraints. Locating at the south end of the camous, Cheeloo's campus chapel shows apparent discontinuity from the grand roofs of other campus buildings,and stands as the only stone building with a cross layout and a flay roof, manifesting the uniqueness of the chapel on campus. However, although it inherits the windows and stained glasses of a gothic church


The Chapel of Jinling with its grand Chinese style roof


The body, layout, and windows of the chapel within Cheeloo takes its main structure in western style, while its roof remains Chinese.


The Chapel of Lingnan University

commonly observed in western churches, the style of its eaves remains Chinese. This type of "hybrid"architectural means was abandoned by Jinling University, which was founded a year before the founding of the Republic of China. The Sage Chapel of Jinling University took the form of a Chinese palace with the two gable walls covered by a complete set of hipped roof. In a different manner, the chapel inside Lingnan University stands as a compromise of Chinese-weternfushion.
From layout to embodiment, the arrangements of these architectures stand as livingtestimonies for the cautiousness and mindfulness of these missionary communities as they fought between "adapting to the nationalism condition of China", earning local acceptance, and sticking to the spiritual identity of a Christian university.
When we inspect the Luce Chapel under the context of campus developmentsof church universities and the historical significance of a campus chapel to Christian higher education, we find Tunghai University to be bearing the grandest land property among all other church universities in Taiwan. Therefore, unlike St. John's, Hangchow, or Dongwu University, which are limited by the size of their lands, Tunghaiis able to follow the examples of Lingnan, Jinling, and Yenjing University, and have a complete set of campus layout plan right from the primary stage of its establishment. Mr. I.M. Pei, the well-known Chinese American architect, set up a clear partitioning system for Tunghai. With Luce Chapel at the center, he built the academic area, administrationheadquarter, spaces of livingfunctions, and dormitories of students, staff, and faculty around it.
The academic area on campus contains the clearest spatial structure: a linear campus mall of 280 meters long extending latitudinally, with three compound of quadrangle college buildings at both sides. Together, library and administration buildings besidethe entranceof the mall formed the academic and administration center of the university. A cluster of linear building units includingcompounds, labtory buildings, and drawing rooms for the architecture department are linked to an inifite geometric datum— the campus mall. Downhill, studentdormitories are also organized as clusters of small compound units developed along the slope, and the faculty and staff dormitory area at the end lies in loose geometric order, similar to the housing units found in suburb America. With an extremely low building density, instead of placing the largest auditorium(Ming Hsien Hall) within the academic area, Pei deliberately chose to strengthen the fuction of the student-faculty living space, and built the hall alongside the Student Activity Center, post office, bus stop, and the key node of the mailroom, which is the message-exchange center in the earlier years of its establishment. This village-like central living space hides quietly in between the arcacias and the flamboyant trees, and is connect to the chapel and the campus mall, which are positioned in a non-geometric layout, through a meandering pebble trail which lies under the trees and the bell tower.
An intricate spatial arrangement set Luce Chapel and the campus layout of Tunghai apart from Cheeloo, Beijing, and Lingnan, which placed their chapels at the dominate center of an axis-aligned space, or a geometric central square or mall: instead of standing at the end of the east-west axis, Luce Chapel stood aside, giving way to an open view of downhill Taichung city and the Central Mountain Range located far at the east. The skyline of the campus' east end is a combination of acacia trees and the endless sky. The location of the chapel only stands conceptually as the center of campus layout. It is placed at the intercession of dormitories, classrooms, library, activity center, and mail room, places of which all student and faculty pay their daily visits. If we zoom in at the intercession, we shall find the chapel standing in the middle of an vast lawn, which is open to all. Student and faculty's daily routines are deep-rootedto this spiritual center, and extend freely to all corners. It was never meant to be the dominant focal point of the campus mall,


The 1959 version of Tunghai'scampus layout plan


The aerial view of Tunghai University in 1965


Luce Chapel under construction. Its location is obviously set aside from the axis of campus mall.


East from the campus mall sits the distant Central Mountain Range as the ending view.


A skyline of acacia trees closes the west view of campus mall.

which is the only place with significant axis-aligned space. Therefore, the form of the chapel was elaborated with a great degree of freedom, demonstrating modern architecural ideas. Its present form is an indication of respect towards the local Chinese community, an attitude which has consisted in church universities for the past hundred years, and the wish forharmony.

As anindividualbuilding erected on top of the lawn, there was no fortress nor fences to defend the chapel's religioussanctity. Although the original model of the chapel made by the actual designer C.K. Chen shows a geometric base on top of the lawn, the final presentation of the base is leveled to the natural slope, allowing anyone to approach, touch, and lie on the chapel. This is an illustration of God being omnipresent for all who are willing to come to Him. Through means of extreme low profile, the architect still deliberately emphasized the divinity of the chapel. All students and faculty are allowed to choose any path that leads to or passes through the chapel lawn.The Art Center sits north of the chapel. Daily activity centers such as Ming Hsien Hall and the mail room are also close by. For a period of time, hymns would be broadcasted at the chapel lawn every afternoon as an invitation to join the chapel's prayer session. This thoughtful arrangement connects the chapel with other campus activities, delivering an alternative hub on campus.

As a university campus chapel, the layout arrangement of Luce Chapel stands out from its forerunners, and opens a new chapter of history for Christian higher education in China. Attached close to the ordinary daily routines, its location reinterprets the definition of centrality on campus.

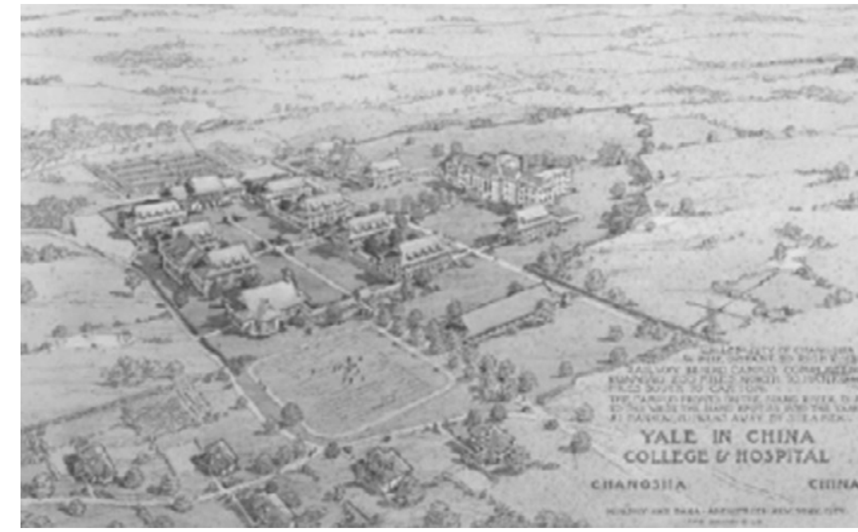
3. As a Modern Architecture

The Luce Chapel is a testimony to the development of Protestant mission in China, and its quest to "adapt to China's nationalism conditions," which lasted more than 7 decades ever since late 19th century. Its actual practices and overall inland reactions did not simply change China's university campus of the era, but also impacted all succeeding church universities including Tunghai.

In fact, the quest of "adaptation" was readjusted time and again. In terms of campus spatial formation, the choice of designer and construction team inevitably became an issue as administrators saught to earn local favors through adding Chinese styles to the campus buildings. For foreignmissionary communities, there were only three solutions: hiring a foreign architect, engineer or missionary who had sufficient professional skills, hiring local mechanics to be under the supervision of the missionary community, or simply hiring a American or European firm that provided all of the above services.

When missionary communities chose the third solution, they often turned to architectural firms,which they had everworked with in the States or Europe. Hiring certified western firms whom they were familiar with to design schools in China is thesimpliest and most reliable choice. However, the problem was that these firms often lacked insights toward Chinesearchitecture, culture, religions. Their inability on bringing in their contruction teams from the States or Europe is also an apparent flaw. Various probable construction issues and unstable telegram syestembetween Far East and the West in early twentieth centuryalso made remote superviseon on design and construction quality an impossible task.

While the second solution appeared to be more plausible, it only worked better on smallconstructionprojects. Moreover, different customs in terms of contract and construction had often cause pause duringconstruction. Execution-wise, the first solution seemed to be easier. However, this also required a branch organization to coordinate with its headquarter in the States or Europe. This time-consuming strategywas high in cost but low in efficiency. By early twentieth century, with a number of construction plans at hand, YMCA began to question the necessity of



Source:Internet
http://blog.sciencenet.cn/blog-2687371-962471.html

persisting in"Chinese style"buildings, and its costlyconstruction budget.

In order to solve the time-consuming issue, by 1916 YMCA had completely relied on the foreign firms opened in the Settlement. This had allowed the branch office in China to makep rofessionaldecisionswithout having to consult its western headquater, directly improving its work efficiency. However, they also held strict demands on the capability and reputation offoreignarchitects in China. When the meansof "adaptation" appeared to be too costly, intense arguments were triggered within YMCA, making it difficult for the branch office to make the final call.

At the time, it was a common belief that "building a Chinese style building means huger financial cost."[6] How to fulfill an underbudgeted design that met all the educational and religious functional demands of the institution had overrided the discussion on the form and style of a building. Gradually, the organization ceased to hold fast to the form and style of itsbuilding. After 1920s, no more YMCA buildings in China were built in Chinese style. In 1922, Sir McMillan gave a distinct comment after a thorough inspection on YMCA's buildings in Asia. He stated that a refined Chinse style building wasinappropriate. For this meant buying more lands apart from what had already been bought.[7] Besides, Sir McMillan also noted that the massive weight of the roof and its wasted space had both resulted great loss in facility.These explicit statements shows his subjectivejudgments. In the same article, he argued that western style architecture has a unique advertisingeffect because for the Chinese it means "progressive". Although this was obviously hissubjective point of view, it had an apparent impact on YMCA's decision-making regarding its choice of architectural style. At least prior Sino-Japanese War, its buildings in China all appeared to be typical western style buildings.

As YMCA began to reveal its intention to give up the Chinese form, some missionary communities still strived to demonstrate their vision of harmony througharchitectural style. Among all the attempts, the renown architect Henry Murphy and his partners, who were well-known fortheir outstanding works and greatreputation, also endeavored to exhibit the quest of harmony through the strylе of numerous campus buildings they designed.Before going to China, his demonstrations of architectural style had alreadyconvinced many church universities affiliated to Yale-China Association. Through highlighting traitsof traditional Chinese architecture, Murphy reassured his clients' expectation of demonstrating technical advancement with respects toward the history of China. From the College of Yale-in-China in Changsha, Murphy successfully built a hybrid campus building with multiple symbolic Chinese and western traits. Its form mostly followed the fashion of Beijing's Palace Museum, which was most westerners' first impression of China. Later, he also took part in the design of Jinling Women's College and Yenjing University. His accomplishment in Yenjing University was theclimax of this architectural trend before the outbreak of war.

"The United Board," which sponsored Tunghai University and ordered the construction of Luce Chapel with the donation from the Luce Foundation, was developed under the aforemenitionedhistorical context of 1920s. This was the era

6. Cody, 2003 p.81
7. Cody, 2003 p.82

when China's nationalism bloomed after the May 4th Movement. People were then appealing for a movement to "retrieve education rights."[9] As we inspect the parallel history of this era, we found that all thirteen christianuniversities were established before the founding of the United Board[10], which means that the Board is an organization that came after these universities and colleges, and did not directly take part in the establishment of these schools. In other words, the United Board was neitherinvolved in the site selection, education system, faculty-student ratio and their interaction mode, nor the form of campus buildings of these universities. We could not specify how many board members had ever participated part of the establishment, just like we could not clarify whether any member of YMCA in China had ever partaken in the founding of any of these universities or colleges. However, the American architect Harry Hussey, who took part in the building of Peking Union Medical College Hospital and went on countless journeys to assist YMCA at the Treaty Ports of China, was dispatched by United Board to join the jury of Tunghai University's campus design competition; that means the members of the Board probably had a chance to understand YMCA's internal disputes regarding the architectural style of its buildings in China.

This provides a valuable orientationto the reasonthat the Board chose a completely different architectural style for its very first university chapel outside mainland China. As multiple universities and colleges already took the fashion of achieving outward harmony through "followingthe Chinese traditional practices," the administrators of YMCA took a rational stand on the necessity of building Chinese style architectures under the quest of"adapting to China's national condition." At the meantime, the pleas to promote the advanced education of the Progressive Era just only focused on the reformation of education systems, and there is nodiscussionconcerningarchitectural form and style.

The appeals of Education system reform of the Progressive Era were extended to the Christian highereducation system in China from the 1910s. Its main concern focuses on the effective management of the fund. This rational concern on the fund stimulated the association of Christian Universities and Colleges in China, the predecessor of the United Board, to invite America's well-known educationalist and theologist,Ernest Dewitt Burtonto analyse the Christian higereducation issues in Far East, especially China. He wrote the famous Burton Papers,in which he advised the board to establishan "East China University" in the East China region, where the density of church universities was the highest.[11] His report can be seen as a beacon ofrationalization among Protestant missionary scoieties in China, and a reminderof thewastes regardingoverlapping investments resulted from the dispersionof church universities. In order to responded to the indigenous nationalism which pleaed for "retrieving education rights",the Republic government gradually institutionalized the development of higher education system and establishednational universityies with comparatively richer national resource and brought. Competition between existing church sponsored and new governmental sponsored universities became apparent .With church universities scattered across the provinces, it was a huge disadvantage for these schools to attract good students and facult members. The Burton Papers specifically suggested the establishment of a regional university as a means to integrate administrative and academic resources. Thus, the concept of "East China University" was formed. Its education system was suggested to follow the footsteps of the University of London. The Board of Truestees of some supportive Protestant Christian universities agreed to activate joint fundraising in the States as the means to control the distribution of fund according to the need of individual budget. To make its opinion count in these university, this became the key measurethe Board used to intervene those schools'internal affairs.

9. After the Ministry of Education(MOE) of the Provisional Government of the Republic of China promulgated the "University Act" in 1912, non-Christian universities began to grow. In 1913, the MOE of the Beiyang Government enacted the "Regulations Regarding Private Universities," which specified the terms and conditions to establish a private university. Following the May 4th Movement 1910, the Beiyang Government furtherenforced "School System Reformation Act," which is also known as the "RenxuShchool System." The years of study for all levels of education was then under mandatory regulation thereafter. All these changes were warning signals for the adventages church universities previously held. Once the Warlord Era ended, more interventions ensued. Therefore, these Protestant Christian universities came together to organize an association. In 1919, all Protestant universities joined to form the Association of Christian Universities and Colleges in China, which held regular meetings to discuss the common educational problems they faced. This is the first organization formed under the purpose of cooperation. The coordinations and collaporations of this association led to the founding of the United Board in 1945.

10. The 13 church universities affiliated to the board were St John's University, which was the first to be established in the Shanghai Settlement, Jinling University(Nanjing, 1888), Lingnan University(Guangzhou, 1888), Hangchow University(Hangchow, 1897), Soochow University(Soochow, 1900), Cheeloo University(Jinan, 1904), West China Union University(Chengdu, 1910), Shanghai University(Shanghai, 1911), JInling Women's College(Nanjing, 1915), Fukien Christian University(Fukien, 1916), Hwa Nan College(1916), and Yenjing University(Beijing 1919). In the same era, there were some church universities which stood independent from the order of the United 10.Board. These universities were Aurora University(Shanghai Settlement, 1903), Peking Union Medical University(Beijing, 1906), XiangYa School of Medicine(Chengsha, 1914), and Fu Jen Catholic University (Beijing, 1925).

11 The church universities affiliated to the Board in East China southern Yangtze River regions included, Nanjing University(Nanjing), Jinling Women's College(Nanjing), Soochow University(Soochow), Hangchow University(Hangchow), St. John's University(Shanghai), Shanghai University(Shanghai).

The idea of East China University was initiated in 1923. [12] Although issues on fundraiseing had hindered the progress,with the mutual agreement of setting up a new university, the"Associated Boards for Christian Colleges in China," the forerunner of the United Board, was initiated in 1932.[13] This associated board was the only North American organization which oversaw thecoordinationsand overall plannings of Protestant Christian universities and colleges in China. However, in less than five years, this establishment of "East China University" was aborted due to the outbreak of Sino-Japanese War. Nonetheless, the war stimulated the practice of joint classes among these church universities.[14] As the boards worked on resettling the universities forced into exile, it also relaunched the "East China University"project. The abandoned project came across the most dramatic turn at 1946 as the board asked the master of modern architecture, Walter Gropius, who created Staatliches Bauhausin Germany,to design the campus of East China University.

Unable toparticipate in the founding of the thirteen Christian universities it later supervised, the board's chance ofleading the establishment of a university came in 1923.Although its plan had been called off temporarily in the 1930s due to theGreat Depression and the Second World War, the "massive donatingpromise" coming from postwar America later regeneratedthe project. However, the question of why the preference of campus design drastically shifted from Murphy's Chinese style architectures to the pure modernism of Gropius remains.Was it simply due to the alteration of appointed designer? Or was it because the quest of "adapting to China's nationalism condition" no longer held a dominate influence on the design, and that the call for changes emerged? The former suggestion seemed to beoversimplifying the cause. An objective and convincing answer can only be found through attending both questions.

As we inspect both the campus design order of East China University entrusted to Walter Gropius by the Board in 1947, and the Burton Papersreleased in 1922, a subtle change is found within the quest of "adaptation" due to China's ascending nationalism in 1920s. As the pursuit of advancement in the Progressive Era took partin the purpose of oversea missions, the quest for "a better system" marched forthamid China's rising nationalism, whichbroughtan inevitable new competition to the higher education market as the new government established national universities. Achieving "unity" among church universities became indispensable and pressing.Even though "unity" was the common consensus, Christian educational institutes sponsored by different missionary societies and denominations across China had already had great accomplishments beforea "coaliation" took place.Therfore, it was difficult to reach an agreement on who was to lead the consolidation. This deadlock lasted during the Eight Years' War of Resistence (the Second Sino-Japanese War) and continued tostagnate after the war. Both the initial suggestion of adopting a "federated" mode of loose coalition with London University being the model, and the postwar suggestion of a "East China Union University"withthe aspect of coalition focused solely on administration, underwent endless negotiations. By the end of the Second Sino-Japanese War, Dr. William P. Fenn, the United Board's director in China who led the development ofProtestant Christian higher education in China at that time, noticed that without a new quest, strategies of coalition would only be empty idealism that fostered the existing stalemate. With the "massive donating promise" from the States, Fenn had enough support to carry out his idea of making a new appeal distinguished from the ones proposed before the war, and sticked to a "rational" practice through reviewing the actual advantages of Prostestant Christian universities in China. This transition to a rational practice was stimulated as the call forunity had been static for more than a quarter of a century due to various disagreements.

12 Written in 1922, Burton Report indicated that before the establishment of the United Board, "Christian Educational Association"already launched "Higher Education Commission" as a consulting organization to promote collaborations of Christian universities in China. The primary goal of this commission was to publicize the ideals behind East China University and coordinate between Christian universities.

13 At the time, any of the aforementioned Christian universities had someone particularly assigned to the publicity and fundraising duties in the States. Therefore the fundraising of Christian Educational Association and the original ongoing fundraising activities of these universities fell into competition. For this reason, ten out of fifteen Christian universities in China agreed to set up Permanent Committee for the Coordination and Promotion of Christian Higher Education in China in 1925. The name of the committee was abbreviated to "Committee for Chirstian Colleges in China in Janurary 1928, then renamed as "Associated Boards for ChristianCollegesinChina."

14 Another version of explanation proposed that Shanghai, Hangchow, Jinling, Soochow universitywas forced to initiate the integration within the Shanghai Settlement due to the outbreak of Sino-Japanese War and the emergence of Shanghai Settlement. After these universities started sharing classes and curricula, Cheeloo and other church universities in exile also began to share classes and curricula at West China Union University. (Liu, Jia-Feng)

From then on, the dominant theme of " adapting to the nationalism condition in China" which had prevailed for nearly half a century had its different connotation. Dr. Fenn realized that with people's growing sentiments of nationalism, a Christian university would always be labeled as "a foreign university"regarless of all its efforts of adopting local traditions. This is a fact and fate that were not going change simply through copying traditional Chinese style architecture or hiring more Chinese faculty and staff members. With this awareness in mind, Fenn went for a non-dogmatic "coalition", which humbly saught the common advantages of Christian academies that all these universities agreed to be apparent in their experiences.Dr. Fenn knew clearly that even with the rise of nationalism, many Chinese intellects undoubtedly took notice of the contributions of these church universities, which are far more important than their foreign identity. As more and more Chinese intellects completed their education abroad and returned to China to join the faculty of these existing church universities, the schools would soon reach the Board's goal ofhaving the Chinese as the majority. The only thing to take note of was the position these Chinese faculty and staff held in these universities, which wasrefering to the concern of whether these Chinese teachers tookpart in the leadership of the school.

In other words, for Dr. Fenn, with all the restrictions imposed by the republic government, keeping foreign managers in these church universities was no longer a choice for the Board to insist. He also thought that these universities were destined to be led by the Chinese, and that meeting the nationalists' expectation would gradually wash away the foreign labels of these universities. However, he also expressed his concerns on the MOE's(Ministry of Education) intervention on the "activities without educational purposes.[15]" He indicated that the "localization" manipulated by the nationalists might interfere the means of education and subdue the great educational traditions of these church universities.

The mandatory deadline for universities to file their registration had forced some church universities in China to adjust their education systems in accordance with the government regulations. As Dr. Fenn reported these adjustments to the Board, usually the Board would only give its consent under the gauranteeof keeping the universities' Christian traits.With this in mind, he decided to review the traitsof these Christian academies. He came up with the conclusion that the Christian traits of a church university were not to be maintained through any declarantions of purposes, but only through the personal integrity and faith of faculty and staff members.This conclusion directly points to the core of education. Fenn indicated that a Christian university is an educational institute that ought to fully acknowledge its academic responsibilities, and used this principal to review the educational "forms"brought up in the discussions of coalition, which had been focusing on the "competitive advantages" of Christian universities under China's rising nationalism in 1920s. He believed thatno Christian universities in China, even the best among them, should be put into comparison with Harvard and Oxford in the West, or Tokyo University in East Asia, in regard to the the scale and quality of funds,equipments, or the reputation of scholars, and that it would also be inaccurate to compare them with the prestigious national universities in China."With the understanding that although the best of these Christian universities in China were able to measure up to the better church universities" (in the West) while most of them simply resembled average American universities, Fenn suggested that it would be more reasonable to adopt the form of American colleges—especially those related to churches—although their curricula were usually very diverse, they were also more competitive. With this proposition, the direction of following the form of small America liberal art colleges emereged. After Fenn expounded on the above proposal, the United Board underwent a

15.For church universities, this type of intervention clearly pointed to the religious activities on campus. However, thes evangelical purpose behind these religious activities were the main reason church organizations set up schools in China.

postwar awakening within theorganization. This was in fact also a desmonstration of its active pursuit in the essence of higher education above all the countless arguments. This form of higher education system provided a out-of-the-box thinking to thetraditional Chinese education system.Meanwhile, it still honored the same context of adaptation in a transitting Chinese society. The image of small liberal art college proposed by Fenn presented a new form of educational form, which was more tolerant, and embraced more possibilities. This was not only a pursuit of"progressiveness" which came with the Progressive Era of the Great Depression in the 1930s, but also a call for the liberal traditions of church universities in China.

After Fenn took over as the director of the United Board, not only did he focus on fostering"theexcellent and outstanding few"and "their specialties in particular academic fields,"but he alsohighlighted the importance of "making distinctions" from the original quest of adaptation. Clearly, this subquest of "distinction" was a response to the many hindrances along the road of coalition. With the postwar "massive donating promise" at hand, it was necessary for Fenn to "find a way out" of the long term stagnation. The aforementioned model of small liberal art college stood as a great reference for the establishment of a new university. The scale limit of this type of school system also met the postwar resource allocation policy of these universities, giving relative flexibility and autonomy for the tryout of the sytem.

In order to earn the recognitions among Christian universities in China, the United Board chose to look for the common factors of the management experiences of these Christian universities. The Board soon found these schools to be sharing similar campus layouts. Moreover, the ways their devoted missionary faculty and staff members utilized campus spaces to teach and mentor their students were also very much the same. All these campus included both an academic area and a residential area. Fenn believed that the residential zones of these Christian universities were their most unique characteristics. Built within or apart from the academic zone of the campus, dormitories and residential area for faculty members were indispensible parts of the campus.[16] Teachers and students shared the same living space on campus. Extra-curriculum activities were deemed to be an emphasiswhich characterized Christian universities.Fenn believed that things that happened outside classrooms are thecritical factors of education, especially regarding the cultivation of a student'scharacter. Fenn further expounded that, social life and extra-curriculum activities are important factors of college life— both for the studentbody at large and individual students, and that the key to differentiate the school life of a church university from those of national or normal private universities is the dormitory area. It has been this way for Christian universities from the very beginning. "Dormitory" always comes first in the campuses'construction plan. With a powerful environment designed for the purpose of mentorship, this type of dormitory arrangement forfaculty and student paved the way for the unique spirit of a church university.

This abiding characteristic of a Christian university had its long tradition within church colleges in China, and provided the establishment of "East China University" a principle statement for its campus spatial arrangement. As the internal demand for "distinction" was reflected on the spatial programming of the university, the Board further expected the campus to display a Christian university's education traits. These anticipations called for new styles and images, and led to the transformation of the long-standing quest of "adaptation," which had had a prevailing influence on the architectural style of Protestant Christian campus in China. As the Board turned to the master of modern architecture, Walter Gropius, who was lecturing in Harvard's Graduate School of Design (a.ka.

16 The truth is, church universities had no choice but to set up dormitory areas under the financial circumstances within Chinese society. At the present moment, therw is no filed documents proving that this was design for the purpose of an educational ideal. When missionaries moved to a foreign city, often times it was difficult for them to rent a housing located close to the schools. When these schools were founded, these educational institutes often bought suburb farm lands or hills located outside the cities due to their limited budget. Before the urbanization of Chinese cities took place, commuting was not an option with the lack of infrastructure. Therefore, it was necessary for schools to provide housing for the students, faculty and staff. This brought about the abby-like learning environment of Christian universities, and developed a unique student-faculty relation andstimulated people's identification with their school campus.

Harvard GSD) in 1947, Fenn and the United Board was clearly driven by the need of "making distinctions." The zeitgeist behind Bauhaus, and the modern architectural movement it represents generated a brand new imagination for the architectural style of East China University, and provided Fenn and the United Board an option different from the traditional forms which had lasted for decades.

This transformation regarding spatial arrangement marked the turning point of campus layoutdevelopment for church universities in China. The establishment of "East China University" opened the door to modern architecture for church universities. The influence traveled far from the establishment of "East China University" to the founding of "Tunghai University" in Taiwan. This proposal of "East China University" was terminated as the communist party took over the political control of mainland China in 1949. By 1952, the communist government halted all the mission activities of church universities in China. The United Board was forced to withdraw its fund in China, and had to look for a new ground to continue its mission. In his famous speech"A New Horizon," Fenn anounced that the name of the board was to be changed from"United Board for Christian Colleges in China" to "United Board for Christian Higher Education in Asia," and that the board was to establish a new Christian university in what was known as "Free China." In this announcement, the idea of"makingdistinction"was no longer a connotation hiden behind the establishment of East China University, but a declaration that the new university would not be a copy of any Christian university in China.[17] Thepursuit of distinction was reaffirmed in this new chapter of history, and connecteddthe campus layout of Tunghai Universitywith the innovationsof its predecessors in China.

A subtle connection linked Tunghai University to East China University. In a collection of the works of Walter Gropius, anannotation on "East China University"project noted clearly that Mr. I.M. Pei, the director of the construction of Luce Chapel, also engaged in the East China University project. In 1946, Pei graduated from GSD and joined Gropius' TAC design team[18], and participated the"East China University" project,which other team members were less familiar with. The spatial taste and culture images of Chinese architectures found its place within Pei's modern interpretation of East China University. When the development of modern architecture under the context of postwar modernismafter 1945, architectswere gradually requested to pay more tributes to local cultures, climates, construction techniques, and architectural systems with thrivingnationalism in the third world and the postwarcurrent of rationalism.In the illustrationsincluded in the projectplan of East China University, linear school buildings are found alongside corridors that enclose individual compound units. With his oriental background, Pei showed clear design intention of integrating western ideals of a college campus with traditional Chinese culture througharchitectural style, structures, and layout model. This can be observed from the few remaining sections and elevations of the project. When Pei graduated from Harvard GSD, Gropius spoke highly of his graduate design, applauding his ability to capture the essence of traditions by keeping what he found to be worth keeping without sacrificing avant-garde ideas. Pei's architectural aesthetics in honor of tradition demonstrated through the East China University Project hit the "distinction" target that the Board was after without abandoning the long term quest of "honoring China's nationalism condition." Dr. Fenn, the executive secretary of United Board with a lecturing history in Jinling University and many years of working experience in China, appreciated this aesthetics so much that he later handed the campus planning of Tunghai University directly to Pei, and gave him the full authorization from the Board.

Pei's participation in the campus design of East China University has a deep connection with his design of Tunghai six years after. This connection is presented throughout all campus buildings including Luce Chapel. The modern construction ideas within is a practical demonstration of the Modern Movement in regard to architecture that started in the West in the early 20th century, and traveled all the way to Asia.

Luce Chapel is undoubtedly a modern architecture with rich connotations hidden behind its simple form and structure that can be studied time and again. However, its historical and cultural significance goes beyond its style and structure, bearing rich and complicated historical and cultural implications that awaits to be rediscovered. It stands as a reminder of where and when Modern Movement in architecture was presented to the East, and its journey of wining acceptance, and its integration with respect tolocal construction systems in the East.

17 The United Board first turned down the suggestion of alumni, facult and staff members from the thirteen Christian universities in China to set up "university in exile" in Taiwan. Dr. Fenn's speech explained the Board's plan on higher education in Asia, and its intention to establish higher educational institutes in places known as Free China(Taiwan and Hong Kong). In 1955, the United Board founded Tunghai University in Taiwan and Chung Chi College in Hong Kong respectively.

18 Mr. I.M. Pei went to study in the States in 1935. He began his study of architecture in Univ. of Penn., which focused on Beaux-Arts, then continued his study inMassachusetts Institute of Technology, where he got his Bachelor of Architecture in 1940. The same year, he enrolled Harvard GSD to study under Walter Gropius. He completed his master degree in 1946. In a collection of the work of Walter Gropius, it shows Pei's participation in the campus planning of East China University.

Conclusion: A Witness to the Encounters between East and West

"The Encounter" of East and West has been a common concept used to interpret the western influence in Asia in the past hundred years, with regard to the invasion and colonization brought by imperialism, and the assimilation or cultural integration besides colonization. Some scholars choose to use the word "meet" to describe the events that happened in a particular period of time, and its cultural indications synchronically. Others use "encounter"to signify the longitudinal impact of westernization and its cultural interactions among eastern communities diachronically.

The accomplishment of Luce Chapel as a classic modern architecture is a combination of western and eastern efforts. It takes the creativedesign of I.M. Pei, who studied under the great modern architect Walter Gropius, with the dedication of C.K. Chen, another young architect who wasdeeply influencedby the modern architectural movement in Illinois,and the collaboration of theconcrete expert, Feng, Hou-San, and ample fundof the Luce Foundation to complete the design and construction of the chapel. However, if we lookedbeyond the making of the chapel,which built in 1962 in honor of Henry Luce, and dig in to the historical context of its formation, we find Henry Luce and thecontribution of envangelim inthe contemporary East-West encounter. Through tracing this part of history at length, we have redefined the historical and cultural implication of Luce Chapel. The historical development of Protestant Christian missions in regard to higher education in China (which Henry Lucetookpart through his involvement in the establishment of Cheeloo and Yenjing University), paints the picture of the East-West cultural interactions by the means of higher education in the late Qing Dysnasty. In contrast to China'slocal private school, academy and imperial examination held by the government for alomost 1300 years, not only did church schools introduce a brand new education system and teaching method, but also innovative campus spatial layouts for learning. The form of a college campus did not take place in China before thefoundings of these church universities. Even as China started to set up its own universities in the 20th century, a chapel was never part of these oriental school buildings. Chapels are only seen in schools founded by Protestant or Catholic churches of the West. Their presence indicated the mission of these schools, and also stands as a necessary means of coherence. In order to "adapt to China's nationalismcondition," these Christian communities carefully chose architectural forms in ways that avoided overruling local traditional cultures. While the forms of these chapels vary in these church colleges and universities, theirs position, style, and spatial sequence that draws student and faculty to the chapel all convey the essential role which Christianityplays in these universities. They also stand as implications for the relation between Christian faith, student and faculty members on campus, and the nationalist ambience and fervor within

their cities.
Luce Chapel unquestionable stands at odds with other campus chapels within church universities in China. Its form resembles the look of a sculpture, risingfrom the central position on campus, where a slope spreads over nearly 3 hectares (7.4 acres) of land inside the campus. Builtnearly 20 meters (328 ft) above ground level, the chapel wasthe absolute tallest architecture on campus. From positioning to the choice of form and style, it stands as the spiritual center of the university. Downhill, the living center of the campus' daily routines lies close by. The position of the chapel is slightly north to the dominant axis drew by the Campus Mall in between the academic area. Thisarrangement allows the chapel to take a style and form different from the college buildings on the sides of the mall without looking obtrusive and incoherent. Thearrangement of the campus layout is also a reinterpretation to the Chinese traditional daily routine which ties temple worships with market activities. This ritual of temple worship after daily shopping duty is so common that traditionally, markets were often found next to temples. Although Luce Chapel still holds a certain degree of sacrosanctity concerning its scale and interior arrangement designed in accordance with the needs of its worship procedures, its disposition is stillarranged in a very friendly and approachable manner. The chapel is no longer simply a place for people to attend religious activities, but a place where everyone pass by daily since it is built on the route that leads to the campus daily routine. This centrality of Luce Chapel varies from all other campus chapels that came before it, and is also highlyinspirational for the building and layout arrangements of secular universities.
The geometric formation and construction techniques used on the building of Luce Chapel also directs to its identity as a classic modern architecture. This indeed marks the influence of its executive architect, Mr. C.K. Chen,its construction engineer, Mr. Feng, Hou-San, and the leading architect of the project, Mr. I.M. Pei, who studied under Walter Gropius, the master of modern architecture. Pei's involvement in the design and planning of the East China University project, which the United Board entrusted to Gropius in 1947, led to the decisive difference between the planning and design of Tunghai, and those of the church universities in China. This also led to the discussion on the reason behind the drastic shift of the deep-rooted quest on"adaptation" in 1947.
When we inspect Luce Chapel under the traditions of China's church universities, we find nationalism within China(especially during 1920s) and the government intervention followed by the establishment of the new government, also had a great impact on the disposition of the chapel. Its form and style is not only an outstanding display of modernism with regard to the techniques and spirits it represents, but also holds historical implications which are just as important.
It was necessary for missionary communities to turn to modernism in respect of architectural form at this particular historical period. Although missionary communitieschose education as the means for evangelism under the thriving nationalism environment of the late Qing Dynasty to win over local acceptance, the development of China's nationalism continued to evolve, its centralfocus and subjects werealso ever changing. As the Qing Dynasty ended in 1910, a new set of regulations for education system was announced by the new government, which intervened educational organizations at all levels. In order to keep the advantages of Christian universities in China, "coalition" became the new focus of all Christian communities in China. This also means that the quest of "adaptation" started to transform. With the call for advanced ideas being introduced through the Progressive Era origined from the States, these communities shifted their aims to unite their strengths to establish a better university instead of keeping existing advantages. This target was also a reflection of the rationalism regarding education systems. With the coalition being stagnated for over a quarter of a century ever since its initiation in 1920s, its development also stimulated rationalism among higher education academies in China. Accompanied by the postwar "massive donating promise" from the States, making "distinction" to represent innovation in education system and educational ideals was a necessary measure for the coalition to progress
Through honoring Henry Luce's dedication on evangelism, Luce Chapel stands as a testimony for the mission works of Protestant churches in Asia. As a campus chapel, it also provides a innovative interpretation of "centrality" in a college campus, the presence of which was new to the Chinese society. When the chapel's constructionwas completed in 1962, all members of the university have been witnesses to this alternative "centrality" through the practices of their daily routines. As a modern archirtecture, its unique form stands out from all the campus chapels in the past, witnessing the conflicts, compromises, and turning points of the long-lasting East-West encounters. Its presence and the way it's presented stand for, and testify the turning point of history.
Pau-tec Han, the former chairman of the Architecture Department at Tunghai University once commented, "Luce Chapel is perhaps the most prominent architecture with the highest historical value. It represents a new form of Chinese architecture under the age of modernism, and is the best production of cultural encounter between China and the western world."With profound historical implications, Luce Chapel stands not only as a commemorativebuilding on the campus ofTunghai University, butalso as a living testimonyfor the less-told stories of East-West encounters!

Elaborating on the Originality of the Design of Luce Chapel at Tunghai University

by Pang, Kang-Chien (Associate Professor, Dept. of Architecture) & Kuo, Chi-Jeng (Professor, Dept. of Architecture)

Preface

Tunghai University started its enrollment in 1955. However, early in 1950, the education circles and Protestant churches in Taiwan had already proposed to the United Board of Christian Higher Education in China (hereafter referred as "the United Board") in regard to the establishment of a university that succeeds the Christian education ministry in China. With the endeavors of various organizations and individuals, in April 1952, the United Board finally decided to locatethe university in Taiwan, and appropriated funds for the founding of this brand new university. In June 1953, the board initiated the preparatory committee of Christian University in Taipei. In the same year, the Board announced the name of this university to be Tunghai University, and that like all its forerunners in China, it is to have a chapel on campus.

Nonetheless, unlike all thirteen church universities established in China, the campus of which had been built intermittently according to the demands of different eras, the entire campus design of Tunghai was handed to the prominent Chinese architect, Mr. I. M. Pei,[1] who delivered the overall layout of the campusand had all the campus buildings following the layout plan to be carried out.[2] Although Pei was the formal architect to whom the campus design was entrusted, since he was also working for the real estate company, Webb & Knapp in New York at the time, he wasn't able to tackle all the details regarding the campus planning. Thereforehe invited C.K. Chen and Chang, Chao-Kang, who also received modern architectural trainings at United States, to join his design team. The three architects, who were all in their thirties, were the first group of Chinese architects who completed their education of modern architecture in postwar America. Their participation in the design and construction of Tunghai's first campus buildings brought about a campus style different from all its predecessors in China. From 1950s to 1960s, sufficient funds from the United Board supported the practice of the highlyexperimental architectures of Tunghai, opening an important chapter of Taiwan's contemporary architectural history. The art of modern architecture was elaborated through the campus of Tunghai University in postwar Taiwan. Among all its school buildings, the Luce Chapel stands out with a structural system, construction technique, and architectural style entirely different from the other buildings on campus.

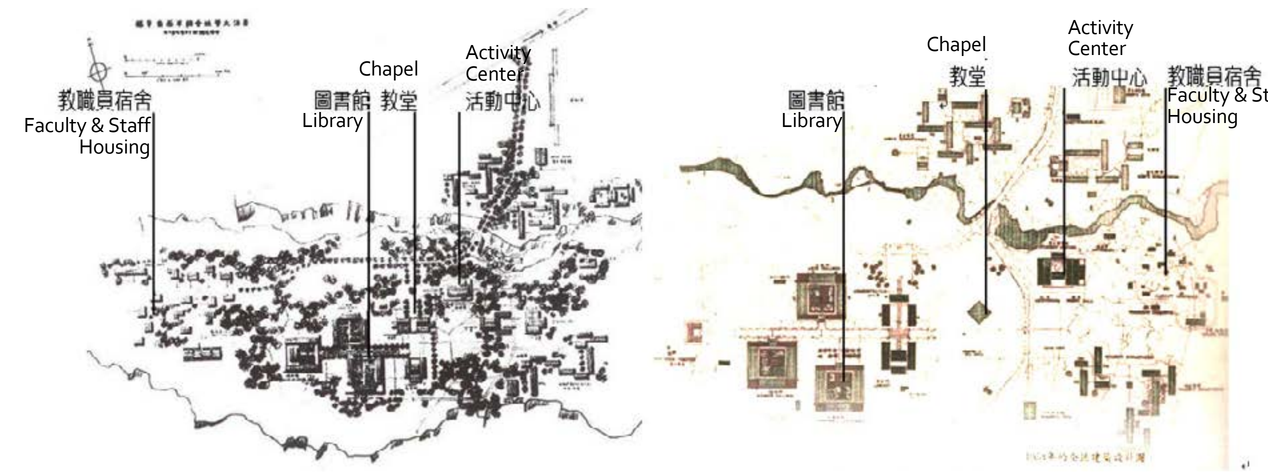
Unlike the campus planning of other universities, the vision of Tunghai's campus arrangement was sketched out through a Chinese brush painting. Instructed by Pei and his description about the landscape about the Dadu Mountain where the university proposed to be situated after his first field trip to Taichung, C.K Chen presented the design team's vision for the campus through a traditional Chinese brush painting(Pic. 1). In the painting, a chapel with a triangular roof is placed right in the center of the campus. North of the chapel, an east-west axis, which later became the Campus Mall, lies ahead of the chapel (Pic. 2). In the painting, we can also see the Central Mountain Range, which lies afar. According to Chen, his design concept was influenced by the linear pattern of the University of Virginia, the campus of which was designed by America's former president, Thomas Jefferson.

1.In 1953, architect Young, Kai-Mei, who was lecturing in Hong Kong University, came to Taiwan to take care of the architectural design of Tunghai University. However, the design of Young failed to satisfy the board's expectation, and stimulated the induced the campus design competition of Tunghai University in 1954 with Mr. I. M. Pei invited as one of the jurors. Nonetheless, Pei commented that none of the 22 submitted designs met up with the educational ideals of the university. On the fifth meeting of the United Board, the board reached the decision of handing over the campus design to I. M. Pei.

2.Besides Lingnan, Cheeloo, and West China Union University and Yenjing University, who also had a master plan for their entire campus layout, the campus layout of other church universities were all developed "organically" according to the demands of different era.

Activity CenterLuce ChapelLibrary

Pic.1 A panoramic of C. K. Chen's vision of Tunghai painted in accordance with essential ideas provided by I. M. Pei.

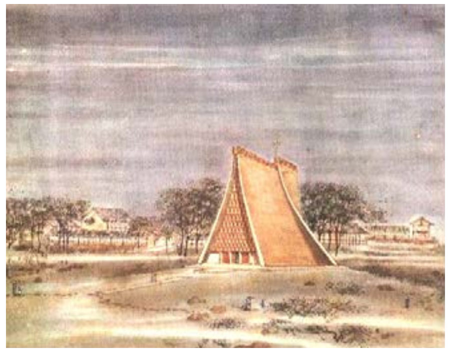


Pic.2 The three central areas of the campus were pretty much the same between the design version provided in July and November 1954. The only difference was that the area of Faculty and Staff Housing was moved from the west end of the campus to the east end. This was a solution to the water pressure issue caused by thewest ascending slope.

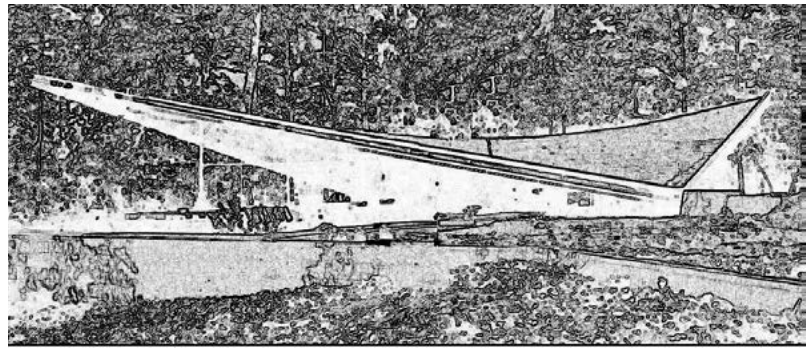
Like the University of Virginia, a wide linear mall formed the dominant axis of the campus. On both sides of the mall grows big trees alongside its colleges and classrooms. This later became the Campus Mall of Tunghai. Early in this initial planning, the concept demonstrated a clear idea of having three central areas: the chapel, library, activitiescenter to symbolize the center of faith, education, and student extra-curriculum activities on campus. For a Christian University, the presence of a chapel does not only stand as the emblem of Christian faith, but holds also the very heart of the school's educational ideals. Behind the Beauson Rd., the library, which represents the core of the school's academic spirit, rises as the first building to locate in the academic area by sitting on top of the Campus Mall. On the other hand, the hub of student extra-curriculum activities is enclosed with Ming Hsien Hall, the mail room, and Student Activity Center.

When the design of the Luce Chapel is inspected under the development of the overall campus construction of Tunghai University, it isnoticedthat the chapel'sconstruction initiated right after all the other major campus building erected on campus. Actually, right after Richard Nixon, who was the Vice President of America at the time, joined the groundbreaking ceremony of the campus in November 11, 1953, the construction of infrastructures such as pipelines and roads began by the end of 1954, following the initiation of campus buildings in the spring of 1955. The library, Ming Hsien Hall, the mailroom, and the Student Activity Center began their construction in 1957, and was completed in 1959. As one of the three central areas of the school, the LuceChapel did not begin its construction until 1962. It was completed in 1963 as the last campus building to be constructed at the founding stage of the university. Why did it take so long? What happened in between 1953 to 1962 that hindered the progression of the chapel?

In fact, the design of the chapel was initiated early in the fall of 1954. Its groundbreaking ceremony was held jointly with the one of Student Activity



Pic.3 The perspective drawingand model published in the Architecture Forum and Architectural Record (The model is currently a collection stored in the library of Tunghai). According to perspectivedrawing and model, the construction materials of Luce Chapel were initially steel and wood. The hyperboloid design can be observed from both magazines. In the original design, the external walls were comprised of a sandwich-like structure, which consisted of three layers of wood with purline in the center. The building was designed to be a building with steel structure, with the sides of the wallstrimmed with U-shape steel bars finishing.This project already had a complete construction blueprint at this stage (the blueprint is a collection stored by the General Office of Tunghai University).



Pic.4 Eduardo Catalano's Raleigh House, North Carolina, 1954 and Felix Candela's Church of San José Obrero, 1959.

Center. However, the construction of the chapel did not begin right away. One of the reasons was that in 1956, Pei was questioned at his speech in Department of Architecture of National Cheng Kung University, which in the meantime is the only professional school of architecture at Taiwan. Another reason was that while the form of the chapel had already been confirmed, arguments in regard to its building materials stayed controversial. Furthermore, the uncertainty concerning its budgetary source also stood as a hindrance to its development.

When Pei spoke at National Cheng Kung University, some people questioned the choice of the sloped roofs, which carries clear vocabularies of traditional Chinese architecture. People argued that architects like I. M. Pei and C. K. Chen, who had professional trainings in modern architecture should present an innovative design pattern. After his speech from Cheng Kung, Pei immediately asked his design team to rethink of an alternative design. Chen also began to study the hyperboloid structure, shell structure,membrane structure, and inflatable structure, which wereextremely popular among the architectural circles at the time. Since these innovative structural systems do not require the support of beam and column structures, they allow architectures to hold a greater span. Pei was not against Chen's idea, and allowed him to take time in exploring the possibilities of breaking away from the traditional beams and columns. This whole process was one of the reasons that delayed the building of the chapel.

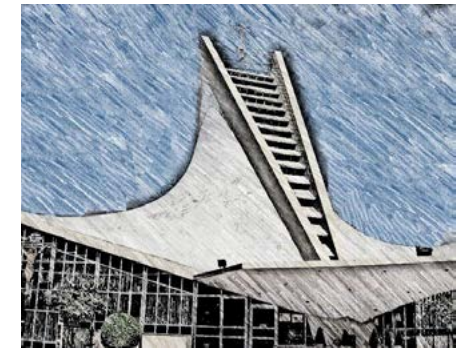
Another cause of the delay was Pei's indecision regarding the choice of construction material. After Pei chose thehyperboloid, shell structure to be the form of the chapel, he kept wavering between a steel structure with wooden finishing, and reinforced concrete. Although the decision on the hyperboloid, shell structurewas published on the Architecture Forum and Architectural Record in March and August 1957 respectively[3], Pei did not reach the conclusion of using concrete until 1960 after meeting Feng, Hou-San.Regarding the construction materials, C. K. Chen once described the problem of constructing the upside-down curved vessel design with wood. While the cohesion of the wooden structure of a ship can be carried through and maintained when the wood swells under water, wooden panels used on architecture is unable to achieve the same effect. Therefore, Chen started looking for an alternative material after Pei' speech in Cheng Kung University[4].

To find the solution, he targeted two projects designed by Eduardo Catalano and Horicio Camilo, who were South American architects teaching in North Carolina, and studied various types of shell architectures they built. Both of their works were based on steel structures with wood or metallic materials applied on the shell exterior walls[5]. Pei also used the curved shell design of the Spanish architect, Felix

3.Not only did C. K. Chen drew a colored perspective diagram on Chinese art paper, he also made a wooden model of the chapel (currently stored in the library of Tunghai University). According to perspective drawing and model published by the Architecture Forum and Architectural Record, the construction materials of Luce Chapel were initiallysteel and wood with a clear hyperboloid design in both magazines. In the original design, the external walls were comprised of a sandwich-like structure, which consisted of three layers of wood with purline in the center. The building was designed to be a building with steel structure, with the sides of the walls trimmed with steel bars finishing.

4.A heated debate on who came up with the idea of the hyperboloid design has persisted. According to C. K. Chen's description to his students, we can tell that he was at least involved in the making of the design.

5.(The Editorial Committee of the Fortieth Anniversary, 2003, pp. 185-186)



Pic.5 Felix Candela, Church of San José Obrero?, 1959

Pic. 6 The inauguration ceremony of the Luce Chapel. I. M. Pei was in the first row. From the very the Left of the second row seated Wu, Ken-Tsung(the boss of the construction company), C. K. Chen, andFeng Ho-San respectively.

Candela as reference. All the shell architectures designed by Candela were built with reinforced concrete[6], which shares more similarity with the actual structure of the present-day Luce Chapel (Pic. 4).[7]

At the time, C. K. Chen also started lecturing in Tunghai and established the Department of Architecture. The design and construction supervision of the overall campus continued with a delay in the design of the chapel.[8] Besides problems regarding construction techniques, the uncertain budgetary source was also a factor that caused the postponement[9]. After much delay, Chen finished drafting by 1961 with I. M. Pei's approval on the design[10]. However, at the time Pei and the other constructionsupervisor, Mr. Chang, Chao-Kang still lingered on the choice of steel and wood as the construction materials[11]. On the other hand, Chen with actual experiences of executing his earlier designs, hoped to adopt reinforced concrete as the solution for the common termite and seismic issues in Taiwan.

To support his design, Chen found the structural engineer, Mr. Feng, Ho-San, who completed his professional training in France, to back up his theory on using reinforced concrete. This had won the approval of the board of directors of Tunghai University. One of the directors of board, Mr. Tsai, Yi-E even wrote to Henry Luce to recommend this design. With the hope to complete the chapel as soon as possible, Luce agreed with the board's suggestion, and decided to go with the proposal of Chen and Feng.

However, as the illustration was being finalized, another obstacle occurred. After Chen completed the construction plan and appraisal12, he sent the illustration to I. M. Pei, who was then in New York. However, the structural engineer to whom Pei entrusted the structural evaluation did not approve the design to be feasible, and asked Feng to join the discussion in New York. Together, Chen and Feng went to New York to expound on their analyses, and communicated with Pei on the design. Meanwhile, the German structural engineer who disagreed with the design suddenly quitted the project. Without his opposition, the design of Luce Chapel was at last finalized, with Pei putting Chen and Feng in charge of the entire construction. After they returned to Taiwan, the construction soon began on November 2, 1962, and was completed within a year. On November 2, 1963 the chapel was inaugurated.

6.(Jodidio, Strong, Pei, & Wiseman, 2008, p. 56) The San José Obrero church Monterrey designed by Felix Candela was completed in 1959. However, Pei's design team including C. K. Chen took Eduardo Catalano's Raleigh House as their reference, which was built in 1954. This shows that the form of the chapel was still undecided in 1960 with Pei also considering the option of using reinforced concrete as its construction material.

7.Questions regarding who started the original concept of the Luce Chapel have always been controversial. It has been an ongoing argument regarding whether the design should be credited to I. M. Pei, C. K. Chen, or the entire design team.

8.In 1960, Tunghai University hired C. K. Chen to initiate the founding of its Architecture Department. At that time he was also working on the Guest House and the Principal Residence.

9.When Henry Luce(Jr.) visited Tunghai in 1960, he thought the chapel had already been completed. When he failed in finding it to be anywhere on campus, he asked the chairman of the board and C. K. Chen. They told Luce that his son, who was in charge of the finance of the project, had withdrew the budget. However, they later found this to be a simple misunderstanding. The case was only temporarily postponed by the son of Luce Jr. because the design, which was still under modification, had a different appraisal at every audit and evaluation of the board meeting. (Hu & Guo, 2008, p. 60).

10.For architecture firms, normally an architect's primary duties are to take orders, supervise the design and constructions of the architecture in addition to the on-going communications with its customers. Usually, there would be a project architect or a project team in charge of the design, construction plan, appraisal, and building license application of a project. Even as the project architect is the person who drew the design and supervised the construction, normally he still won't be the nominal architect of the project. The nominal architect of a project will only be the architect who takes the design order, supervises, and finalizes the design. In the building of the Luce Chapel, I. M. Pei was the architect who took the design order from the United Board with C. K. Chen being the project architect. On the campus design project, although Pei was providing voluntary service without getting paid, the United Board still paid Chen as the project architect. Nonetheless, Chen once mentioned that he still had to report to Pei on the ideas and construction methods of the campus design. Moreover, the campus construction plan was marked with the label of I. M. Pei & Associates instead of having the signature of one particular architect. When Chen changed the construction materials of the chapel from the original steel structure to the present reinforced concrete, he put in great efforts in finding Feng, Hou-San to support his design, and to persuade Pei in New York. Even though various information shows Chen to be the overall designer and executor of the construction supervision, from the photos taken in the inauguration of the chapel, Pei still took the seat in the first row while Chen and Feng took the second (Pic. 6). After the ceremony, Pei even joined Pastor Lien-Hwa Chow and other representatives of the United Board on an aerial tour of the university, indicating Pei to be the titular head architect of the Luce Chapel project.

11.The library of Tunghai University holds a structural diagram drew by Roberts & Schaefer Co., a company known for its long and rich experience in giving consultation concerning structural engineering. The chapel stays much the same with the style, height, and proportion of the chapel in the diagram. This shows that Chen and Pei had reached to a mutual agreement on the design by then.

12.At that time the overall budget was 150,000 USD, in which $100,000 was for construction and $50,000 for expenditure on administration, which included design charges, costs on configuration, water and electricity, travel expenses, and taxes.

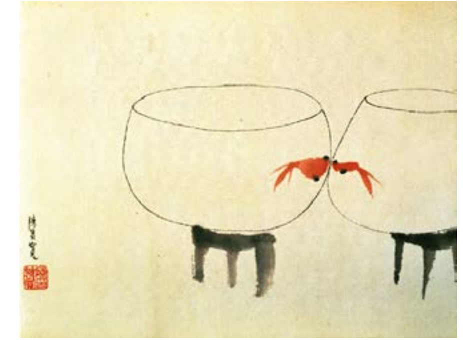
The Original Ideaof the Chapel- the vision of a chapel within an oriental campus visualized through a traditional Chinese painting

In the article "On the Design of Luce Chapel and Its Construction," in which C. K. Chen mentioned the prototype of his design, Chen explained that "the form of chapels in western countries and all religious architectures of different eras have always been architectures that demanded the greatest minds, manpower, and material resources. The presentations of these architectures are cultural reflections of their eras. After hundreds and thousands of years, they still stand as beacons of history and traditions for generations to come. My vision for the chapel of Tunghai is the same. May this architecture be a reflection to our culture and traditions, demonstrating the will of Christ, His love and sacrifice, alongside the creativity and spirit of the zeitgeist of its era." This statement addressed the issue[13], which the designer was facing at the time. As Chen designed the chapel, besides tackling on administrations details (such as construction appraisal and progress estimation), engineering techniques (reinforced concrete or wood), spatial design(regarding the significance of the architecture), the design team led by Chen and Pei also had to deal with outsiders' concern and advices in regard to the chapel. Being the first university that the United Board established in Taiwan, many expected the school to carry the traditions of the thirteen church universities sponsored by the board in China. Among all the customer and user demands, it was utterly important for the design team to incorporate oriental elements as it was designing for a chapel that locates in the Free China(Taiwan). Ultimately, a hexagon plan, lined sky windows, along with golden glass tiles was chosen as the means to incorporate Chinese architectural elements. This is one of the reasons why the Luce Chapel is celebrated as a classic Chinese modern architecture.

With a legendary head start, the campus compound structure of Tunghai is illustrated through Chen's unique brush painting. At the right side of the painting, an axis cuts through the compound sections. This axis is the present-day Campus Mall. Left from the axis sits a structure with folded diamond surface with the form of a triangular roof with a tower erected alongside the building. This is Chen's original idea of the chapel. At the top and bottom of the axis where the three compounds clustered next to the chapel are the faculty and student dormitories and the activity center, respectively. The dormitories and activity center are separated by a foggy forest and small valley. As the theme of design was expected to include an illustration of the East-West encountering, Chen managed to embody the "East" through demonstrating the highest form of Chinese art, "the artistic concept," thereby establishing the relation between campus buildings. This means that the design of the Luce Chapel was a part of this artistic concept of overall campus design, and that through this artistic concept, the relation between the campus and the remaining school buildings was set. The form of the Luce Chapel takes an architectural language different from all other campus buildings, signifying its unique situation as the spiritual emblem of the university. Its position intricately slides away from the axis of the Campus Mall, allowing the terms of its formation to be carried out separately, and paved a way for the ideas and principles of modern architecture to be freely maneuvered in its design.

Hang, Pao-Teh once made a comment on Luce Chapel, stating that "this chapel is perhaps the most renown architecture with the greatest historical value in Taiwan. It represents the new trend of Chinese architecture in the modern era, and is the best production of the Chinese-western encounter."[14] This "encounter" between the East and the West is an important aspect in regard to the design perspective of the Luce Chapel. From the golden yellow ceramic tile on the exterior of its shelters,[15] including the formation of the congregational space enclosed by four simple walls, the space of the chapel reveals the modern aesthetic principles

13 C. K. Chen "On the Design of Luce Chapel and Its Construction," The Online Archives of the School History of Tunghai University. (Chen 1963)
14Hang, Pao-Teh "Architectures and Its Surroundings: C. K. Chen and His Architectures" (Chen, 2003, p.21).
15 I. M. Pei rarely explains about his design ideas of Luce Chapel. He once mentioned that being far away from home, he blended in the roofs of the Palace Museum in Beijing and the golden rooftops of ancient Chinese temples with the dramatic roofs of gothic cathedrals of the West to build a solid pyramid. By holding a touch of home, he made a comprehensive fusion of both culture. (Jodidio, Strong, Pei, & Wiseman, 2008, p. 56)


Pic. 7 C. K. Chen, "Have Little and Gain", Lithography, 32x62 cm, 1977

interpreted by these Chinese elites who received modern architectural trainings in the early twentieth century in the United States.

Through displaying the East-West encounter through presenting the "artistic concept," Chen once mentioned that he had adopted the Chinese concept of "simplifying the complicated" to reflect the "less is more" concept proposed by the famous German American architect, Ludwig Mies van der Rohe (1886-1969), who was well-known in the Modern Movement in architecture. Deeply influenced by the traditional Chinese aesthetics and philosophy, the architectural designs of Mies often leave a vast empty space alongside his cutting-edge simple forms. Mies used "less is not empty but lean, more is not crowded but complete" to express his architectural philosophy. On the other hand, Chen used his brush painting, "Have Little and Gain" (Pic. 7) to illustrate his perspective on simplicity, stating that his work is "a demonstration of the Taoism theory of "have little and gain," quoted from the book "Laozi," which conveys the belief of "Have little and gain; have more and be confused." In his paintings, Chen preferred using simple strokes to carry deep and profound implications. Likewise, when he design for the overall campus layout of Tunghai, he chose to use subtle artistic concepts to frame the layout of the entire campus, and left spaces for imaginations regarding the possible experiences and emotions within the"movements" of peopleon campus. He believed that "if he had said more, the significance would have been limited. Whereas, thoughts were often provoked when he spoke less." Therefore, he deliberately left room for his audience to imagine and think[16].

The aesthetic perspective of the "artistic concept,"originated from Chinese paintings was not only used on building the relationship between campus layout and the buildings within it, but also on the design of its chapel. On top of the widespread lawn, four parabolic conoid curved walls enclose a simple hexagonal diamond plan, forming a congregational space without beams and columns. The top of the building is closed with two lined sky windows, while the east and west ends of the building bring in silhouettes of trees from its surrounding environment. Even though its architectural form is extremely simple, the designer's thoughtfulness can be observed from the details of lighting and building structures.

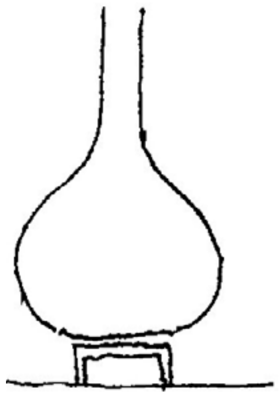
Peering into the craftsmanship of the chapel's design

1. Manipulating light

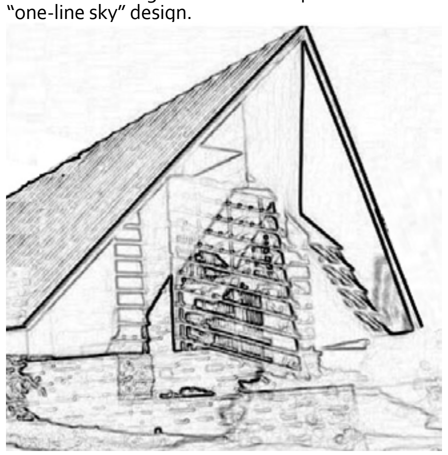
In the history of church buildings, "light" has always been an important element, for the Bible uses light to imply God. "God is light"[17] has been a concept adopted in church buildings as a demonstration of sacredness. The father of gothic architecture, Abbot Suger (1081-1151) believed that the color changes of light refraction could strengthen the congregation's belief on the presence of God. Therefore, in the past lights were seen as a medium of divine intervention in chapels and churches. Suger conveyed that God's teachings and image could only be properly embellished through the transparent and translucent light effect of glass, and that this is the only way to convince mankind of the heavenly voice on earth[18]. The German writer Paul Scheerbart (1863-1915) also illustrated his idea on glass being the emblem of moral emotions in his novel "Glass Architecture." In the novel, he pointed out that the image of "light" carried through glass architectures uplifts spirits and morality[19]. From the very beginning, chapel designs have shown attempts to bring in light through various means, and create emotional projections with respect to the relationship between God and mankind. Likewise, Chen also pondered on the relation between light and space right from the initial stage of his design.

The chapel within the brush painting of the campus that C. K. Chen painted at

16. (Hu & Guo, 2008, p. 102)
17. "This is the message we have heard from him and declare to you: God is light; in him there is no darkness at all." (1 John 1:5, the New Testament of the Bible)
18.Chu, 2001, p. 88
19.Chu, 2001, p. 92



Pic.8 Chen once mentioned to his student on the development of lights within the chapel: One day a colleague within I. M. Pei and Associates went to Chen with a sketch of the section of a vase, which sits on top of a pedestal. The top the vase exists a hole that leads to the space within the vase, this sectional drawing was later developed into the "one-line sky" design.



Pic.9 A chapel design, which incorporated the image of folded prayer hands in the east. First Unitarian Society of Madison, Wisconsin, USA, Frank Lloyd Wright, 1947.

Pic.10 The changes of lights during regular Sunday services within the chapel.

his earlier design stage shows apparent difference to the present-day chapel, which consists of four curved walls[20]. In fact, the original idea of an upside-down wooden boat only included two walls, and the idea of "curved wall" also wasn't part of the earliest design of the chapel. It was due to the comments regarding the lack of light on the sides of the chapel that made Chen broke the two walls into four. The concept of having four walls thus emerged with openings on both sides, which naturally became the side windows. In order to distinguish the discontinuity of the walls, the two back walls were made higher than the two front walls. When Chen demonstrated the model to the board of directors, Mrs. Ferguson remarked on the appearance of straight sidewalls to be too stiff, and advised Chen to apply the curves of a Chinese roof[21]. Taking the advice, Chen finalized his design with four curved walls[22].

Han, Pao-Teh once pointed that C. K. Chen was much influenced by western chapels built during the age of modernism. This was a time when chapels and churches gradually started to adopt simple triangular forms like the Unitarian Church (pic. 9) in Westconsin built by Frank Lloyd Wright, who was recognized as the father of American architecture. Chen's design resembles the folded praying hands of the east, and comprises an image of open palms, which illustrates the significance of a form that symbolizes the humbleness lies within humanity in seeking of a heavenly existence[23]. It also bears resemblances to an upside-down vase, or ship. Multiple elements contributed to the form of Luce Chapel. This includes construction methods, choice of materials, and pragmatic operations and metaphysical concepts. Chen once gave an annotation on the relation betweenthe walls and lights, stating that the side windows in the middle section light up the altar, which adds a sense of mystery with the lighting effect (Pic. 10). To simplify the construction at the intersection of the curved walls, the two curved walls at the back were made higher to create an overlapping look. The section built with higher walls is also where the inner altar lies, manifesting the significance of the space with itshigher appearance.[24]

With the decision on using simple walls to enclose the congregational space made, the next challenge was drawing lights into a structural system without installing windows on the four curved walls. The solutionabout the lined sky windows came up in a conversation within the design team[25]. After reconsidering the whole structural system of a sheer modern architecture, Chen pointed out that the four walls should be completely separated with a disconnected rooftop that forms a lined skywindow to solve the issue of insufficient nature lights, and to stay within

20.The fortieth anniversary special edition of Tunghai's school history includes an interview with C. K. Chen. In the interview, Chen recalled a meeting Pei hosted in his house for the discussion on the chapel design. Pei set up a very romantic atmosphere in hope to stimulate some design ideas, which eventually failed when no one came up with any good ideas. Later, Pei suggested a gothic dome by demonstrating through hand gestures, and proposed using brick as the construction material. However, Chen thought the design was inappropriate concerning the frequent seismic activity in Taiwan. Afterwards, Chen built his first model with wooden sticks, finding it to resemble the look of a wooden ship. The design team went for a wooden structure thereafter. Some people even said that Noah's Ark from the Old Testament is the source of the chapel's design idea.
21.The Editorial Committee of the Fortieth Anniversary of Tunghai University, 2003, p. 243
22.The hyperboloid curves of these four walls developed into the parabolic conoid walls, which enclosed the bottom diamond shape surface with a linear sunroof high up in the air. The bewildering conoid curves of the roofs match the curves of a Chinese saddle roof. Ref. C. K. Chen 1963.
23.Hang, Pao-Teh "Architectures and Its Surroundings: C. K. Chen and His Architectures", Ref. Chen, 2003, p.23.
24.Ref. C. K. Chen 1963.
25.Chen once told his students the story behind the development of lights within the chapel: One day, a colleague within I. M. Pei and Associates went to Chen with a sketch of the section of a vase sitting on top of a pedestal. The top the vase exists a hole that leads to the space within. This sectional drawing was later developed into the"one-line sky windows"design.

Pic. 11 An aerial view of the campus taken in 1965, which was a few years after the completion of the chapel. (Noting the gym next to the sports field is actually a structure bigger in size, however, to keep the chapel as the highest building at the campus skyline, a graben was dug to lower the ground level of the gym.

the modern structural principles of the building. Thus, the "lined sky window" became a reasonable and yet dramatic solution.

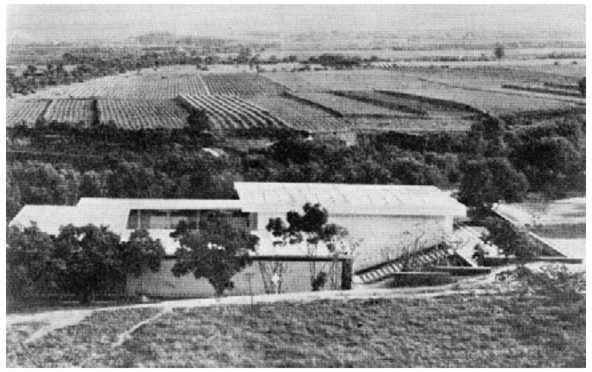
Besides the dramatic effect of the "one-line sky" on the top of the ceiling, in order to draw in more natural lights to the interior for daytime church gatherings, Chen utilized the east and west openings of the hexagon surface to optimize the focal points of the chapel. Both ends consist of glass walls that extend from the top to the bottom of the building for lights to pierce through both the east and west ends of the space, creating links to the outdoor nature for the congregation to enjoy views of tree shihouette during indoor worships. Parallel curvatures in between the sidewalls on the north and south surfaces created curved openings, which eventually becamethe side windows. During every Sunday worship, the morning light would penetrate through the curved south-facing side window and lights up the cross at the center of the altar (Pic. 10). Through the "lined sky windows," a straight line is projected to the central aisle, which is also the center of the hexagonal surface. Together with the east and west floor-to-ceiling windows, this central axis has accentuated the worship focus, making light the specific medium that signifies God's presence in the Luce Chapel.[26]

2. Expressing the relationship between God and man through its site planning

As aforementioned, the design of the campus of Tunghai began with a brush painting, which made the actualization of the artistic concept a primary task of the design. In the brush painting, a vast lawn locates next to the chapel with a tall tower that matches the look of the chapel, highlighting the clear monumentality of the chapel to the entire campus. In terms of "Monumentality", the master of modern architecture, Louis I. Kahn defines the term to be "a spiritual quality inherited in a structure which conveys the feeling of its eternity, that it cannot be added to or changed", and that architectural monuments reveal a striving for structural perfection which has contributed in great part to their impressiveness, clarity of form and logical scale.[27] The "monumentality" which Kahn implied is a spiritual quality thathas been distinguished from the characteristics of architecture. In comparison, for the design of the Luce Chapel, besides the monumentality created by the building itself, the chapel also holds a distinction from its surrounding architectures. Along with the particularity of its circulation formed by its specific location, which was arranged at the very beginning of the founding stages of the university, the monumentality of the Luce Chapel is strengthened in every aspect.

Rising from the vast lawn at the intersection of the main circulations on campus, the Luce Chapel indeed occupies an excellent position to be a monument. Without anything standing on top of the spacious lawn, the volume of the chapel becomes the natural focal point (Pic. 11). For the chapel to remain as the focal point, the Art Center at the south of the chapel also designed by C. K. Chen was lowered to manifest the monumentality of the chapel. At nearly twenty meters in height,[28] he lined sky windows marked the highest point on campus. Before the trees shaded the sky, the cross on top of the horizontal linedrooftop was visible everywhere on campus and even on the nearby roads off campus, highlighting the chapel as the pivot of the school's Christian identity.

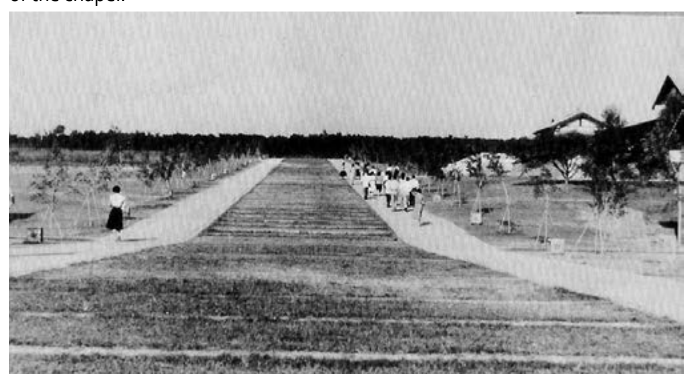
26.In around 1990, two meters of wooden panel was added to the screen behind the altar to place the gigantic speakers of a newly purchased electric organ. The viewof the west ceiling-to-floor window was thus covered partly, causing a huge impact to the original lighting design of C. K. Chen. When Chen returned to the chapel to receive an honorary doctorate degree after he was granted the National Award for Arts, he refused to take photos in front of the altar after he noticed the change. In April 2015, the church bought another new electric organ. The latest technology has dramatically reduced the size of the speaker. With the on-going conservation research project initiated by the Getty Foundation alongside the consultation of the architectural acoustic expert Albert Xu, the screen was lowered to a height close to the original design without reducing the high frequency sounds, hence restored the wooden screen to its former glory.
27.Ockman & Eigen, 2007, pp. 48-54
28.In fact, measured from the base to the lowest point of the roof, the university's two-storey gym is 13.9 meters tall. However, with a wide span, its steep roof adds another 6.1 meters to the building. Along with the foundation, the gym consists a height of 20.2 meters in total, which is slightly taller than the chapel at 20 meters. In order to keep the Luce Chapel as the highest building on campus, Chang, Chao-Kang chose to raise the budget of the gym and dug a graben 7.2 meters deep (even at the lower section down the slope the graben was as deep as 3.4 meters), and built the gym on top to form an external appearance of only thirteen meters in height!



Pic. 12 C. K. Chen Art Center 1963-An upside downshell building

Pic. 13 Art Center (at the right hand corner of the picture), hidden at the south of the chapel.

Pic. 14 The view along the slope east to the Campus Mall



Pic. 15 Uphill the Campus Mall lays the view of the acacia forest and the open sky.

Pic. 16 Before the Banyan trees at the sides of the Campus Mall grew to cover the view to the east, the off-axis position of the chapel could be clearly observed.

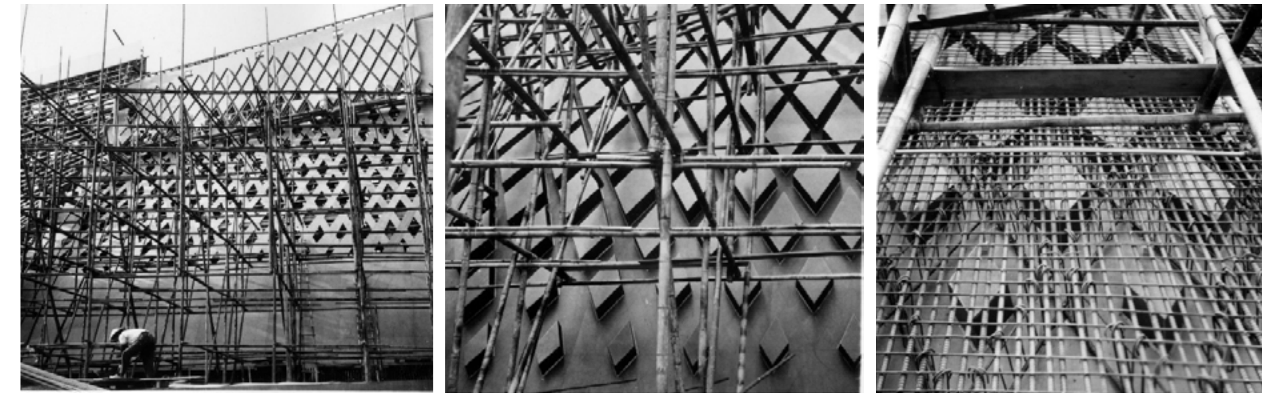
By averting the east end of the Campus Mall, the chapel gave way to the Central Mountain Range(Pic.14) and the acacia forest(Pic.15) to be the skylines east and west to the mall. This development is a demonstration of the "artistic concept" of the campus design. As both the east and west ends of the campus avoided placing monumental vistas, the Chinese philosophy of having "harmony between nature and mankind" was actualized through the campus layout[29].

With the chapel sliding away from the central axis[30] (Pic.16), Chen set up a sophisticated spatial interpretation full of rich connotations. As a church university established to promote Christian ideals, Tunghai was destined to have a chapel. While the importance of the chapel is demonstrated through the positioning and architectural style of the building, students and faculty are the most essential members of the university. The colleges at both sides of the Campus Mall are where pursuits and exploration of acknowledge take place, thus stand naturally as the center of school life. By stepping away from the axis, the chapel gave way to the academic identity of this higher educational institute, implying the less dominate role of the church in the academic area of the university.

Concerning the location of the aforementioned position, the administrators of Tunghai also thought out the possible roles of the chapel on campus and its relation to its neighboring communities. With the help of Professor Jack Graham, who was dispatched to the university by the United Board, the role-orientation of the chapel was defined as a parish church set to serve the small community formed by students and faculty members, which involved a total population of eight hundred people at the time. Besides functioning as a place for Sunday worships, the church also needed spaces for its office, Sunday school classrooms, Bible studies and fellowship meetings. However, due to the chapel's "monumental" functional setting, adding too many accessory areas would have complicated the form of the chapel, and violated the principle of "form follow function" in modern architecture, which was much against adding superfluous elements. This is the reason the team concluded "the place of gathering[31] "to be the only role-orientation of the chapel. In the aforementioned interview, Chen explained this development of the above solitary function of the chapel. As the church building was set up to function as a chapel only a chaplain's office was erected subsequently to meet the demand of all other accessory functions. Without additional accessory spaces, the chapel was able to stand as a place set up solely for the purpose of gathering. Its only accessory spaces are the dressing room and toilets beneath the altar to serve the ministers and choirs. With this simple functional setting, the chapel was allowed to maintain its consistency in between form and function.

29.Professor Fu, Chao-Ching at the National Cheng Kung University once addressed the contemporary and traditional significance of the Luce Chapel. He believed that "the achievement of Luce Chapel has to do with its relationship with the remaining school buildings and the overall campus layout. Undoubtedly, the chapel stands as one of the key buildings on campus. After C. K. Chen took over the design of Tunghai's campusbuildings from Chang, Chao-Kang, the architectural style shifted dramatically. The architectural style Chen adopted was a cutting edge choice of its time not only for Taiwan, but also for the world. The direct proof of the building's Chinese character lies at Chen's depiction on the resemblance between the curves of a conoid shelland the Chinese saddle roof. The umbrella-like structure of the Art Center also reflects the spirit of a Chinese architecture. Its hyperboloid roof with grand eaves looks like one single curve from the side. The look is a natural result of the heavy rooftop. At the bottom, the wooden structure supports the roof caps, holding the stable equilibrium of the architecture, and reflects the sunward character of a Chinese saddle roof. Ref. Chen, 2003, pp. 190-202

30.The interview with C. K. Chen in the school's fortieth anniversary special edition of the university's history, Chen specifically expounded on the off-axis position of the chapel. "At that time, the central line of the chapel was aligned with the roofline of the administration building. However, when we inspected the construction layout of the chapel, we realized that from the inside, the view to the west would end up with a roof, which was not an ideal landscape…In order to avoid blocking the view of the Central Mountain Rounge from the Campus Mall, we decided to place the chapel in between the axis of the Campus Mall and the administration building instead of aligning its roofline. We also grew a row of tall Banyan trees in between the east end of the administration building and the chapel to avert the view of the administration building inside the chapel. For I. M. Pei, the off-axis practice was the means to "extend the openness" of the chapel. Nevertheless, the west view of the Campus Mall was blocked by the new library built when Dr. Mei, Ko-Wang was the school principal. The school buildings constructed thereafter started to violate the original principles of the campus layout. Ref. The Editorial Committee of the Fortieth Anniversary of Tunghai University, 2003, p. 242 & Jodidio, Strong, Pei, & Wiseman, 2008, p. 55



Pic. 17 Through the framework revealed from the photo record at the formwork stage of construction, the diamond-shaped lattice beam clearly appears to be wider at the bottom and narrower at the top. (Photo by C. K. Chen)

3. Technical Experiments and the Breakthroughs

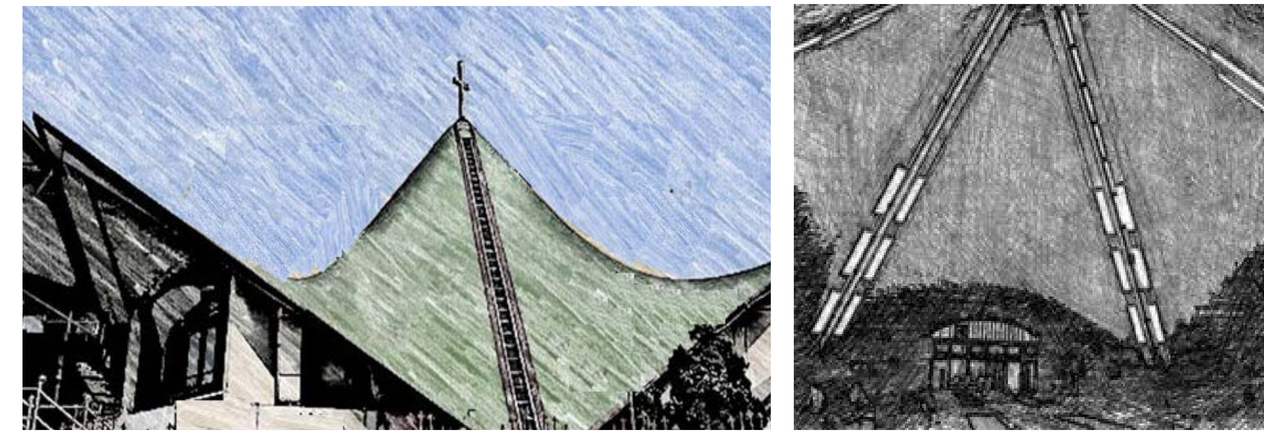
After the design had been determined to be a congregational space enclosed by four walls, the relation between the walls became one of the focuses with respect to the structure and construction of the chapel. Although Mrs. Ferguson, one of the board directors of the United Board, contributed the key advice of changing the structure from straight lines to curves, the main principle adopted to the final solution was that of a conoid structure. All four walls are separated but symmetric in pairs. The taller but narrower pair enclosed a trapezoid plan that became the altar space where speakers, emcees, and choirs stand and sit during worship hours. On the other hand, the shorter but wider symmetric pair formed the congregational seating area. Unlike most conoid structural system, which

31.The Editorial Committee of the Fortieth Anniversary of Tunghai University, 1995, p. 241

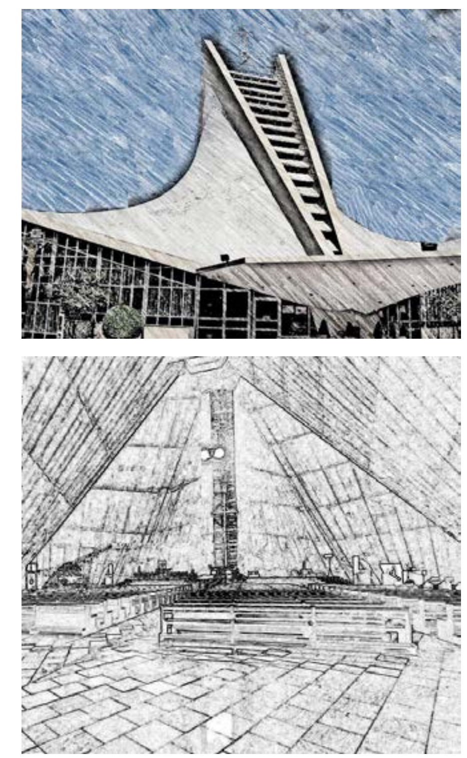
Pic. 18 The four walls of Luce Chapel connected by the concrete joints at the ceiling. (Photo by C. K. Chen)

consists of shell and beamless structure, the Luce Chapel adopted lattice beams to its bare walls. This is also a reasonable choice of structure. Instead of four heavy shell structure, the force of the four curves is distributed through the rib beams to reduce the weight of its structure, enabling the walls to hold its own weight for the parallel interval in between the two symmetric pairs of conoid walls to be deftly hinged instead of sharing the paired other side's weight by fixed joints. These hinge joints not only balance the horizontal forces brought by earthquakes (as the hinge points synchronize the movements on both sides, this avoids the walls to crash into or pull away from one another during the horizontal shifts of a seismic activity), but also made the original lined sky window idea possible (Pic.18).
In other words, by exposing the diamond-shaped crisscross rib beams, the design unveils the physics of the structure, and echoes the bare rib beams on the exterior of a gothic cathedral. Both rib beams act as a guide that leads the eyes of the congregation upward. Chen explained that this was an twentieth-century attempt to combine the traditional gothic architecture with the curves of a Chinese saddle roof. Since the greater curvature generate heavier bending moment at the lower part of the curve, the cross-sectional area at the bottom of the rib beams was amplified to strengthen the structure. Through the careful calculation of the structural engineer, Feng, Ho-San, the diamond-shaped rib beams exposed at the bottom part of the inner walls appeared to be uncommonly solid, with the cross-sectional area gradually decreasing as the walls reach the top of the building(Pic.17). This type of arrangement is not only fitting for the force distribution according to structural principals, but the gradually decreasing rib beams also accentuated the visual focus for the congregation from the seating area. Moreover, this also created a visual effect that extends the interior height of 19.72 meters. Some also believe that this was designed to echo the techniques used on gothic religious architectures in the distant West.
Pei interpreted the structure of the chapel through a different perspective. He believed the design of the lattice beam was to avoid an overload on the concrete shell structure. These exposed supporting ribs make the force distribution visible and clear[32]. However, the truth is, with the "ribs" been exposed, the structural tension and compressionof the building is also overt and mind-blowing. If they had been hidden, the focus of the interior would have been the form of space instead of its structural mechanics. Upwards, the RC hinge joints at the rooftop is arranged remarkably. As the four curved surface meet at the rooftop, these joint connections sustain the complicated tension, compression, bending moment and shearing force of the overall structure. Right out on the top, the cross rises high in the air as a manifestation of the omnipotent divine power of God.[33]

32.Jodidio, Strong, Pei, & Wiseman, 2008, p. 57
33.C. K. Chen, 1963



Pic. 19 C. K. Chen The facade and interior of St. Paul's Episcopal Church in Kaohsiung, 1965

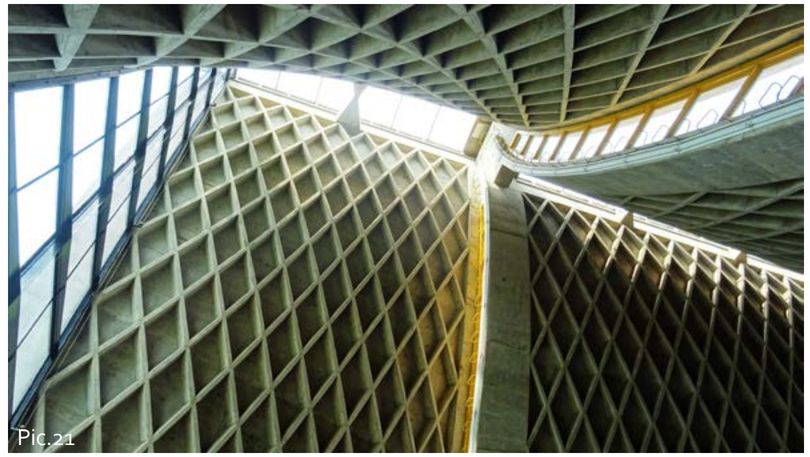


Pic. 20 Kenzo Tange Tokyo St. Mary's Cathedral, Its facade and interior, 1964.

In comparison to the shell structure of St. Paul's Episcopal Church designed by C. K. Chen in 1965 (Pic.19), there is no rib beams in the inner surface of the shell, that also means it give up the opportunities to express its construction and details. Kenzo Tange's St. Mary's Cathedral (Tokyo Cathedral) designed in 1964 (Pic.20) also adopted a shell structure, but its internal wall did not apply the lattice beams. By exposing the diamond-shaped rib beams, the visual effect within the Luce Chapel was further amplified. According to Chen, he also wanted to be one of the first architects to try out this modern technique. Therefore, as he heard of Tange's coming St. Mary's Cathedral, Pei asked Chen to speed up the case and complete the work as soon as possible. Chen fulfilled the mission by finishing the Luce Chapel a year ahead of St. Mary's Cathedral. The diamond-shaped lattice beams demonstrate the elegant curves of the chapel, and express the overall structural order of the building. The wall is 60 cm thick at the bottom of the wall, and is reduced to 27 cm at the top. Likewise, the width of the lattice beams is 75 cm at the lowest level, and decreases to a width of just 8 cm as the wall reaches eight meters and above in height. In order to decrease the risks of resulting a "honeycomb"[34]at the vertical corner upon demolding, the entire rib beams adopted a 45 degree chamfer which made the lattice beamsabove eight metersheight(which all keep its width in 8 cm only) appeared to be slender than the bottom. The diamond-shaped lattice also contributes in accentuating the linear proportion, adding the sense of sublime fulfillment to the skylight above. The diamond-shaped lattice frame is smaller at the bottom, whereas the ones on top grows bigger. This logical structural solution clearly demonstrates different forces distribution of the structure. Without covering the construction interface[35] created by its height restrictions, this type of exposing construction materials delivers a visual tension through the diamond-shaped lattice beam. Beside the rationality and absolute geometric order, traces of its handwork also remain visible.
In terms of its overall structure, the precision of the construction mainly is reflected on the four conoid walls of the Luce Chapel. The gradual transformation at the solid frames of the rib beams and its hollow latticework is an excellent display of geometric aesthetics, and createsa visual flow within the chapel that leads the eyes of the congregation upward upon their entrance. This religious saintliness is created by the modern geometric aesthetics and architectural technique similar to the traditional gothic church, which are high and erect to manifest the greatness of God. The lattice beams at the inside share the same ratio with the diamond-shaped ceramic tiles on the exterior of the conoid walls. The same geometric pattern is consistent inside out with the curves twist and turn according to the equation of a conoid pattern. Along with the irregular diamond-shaped lattice

34If the concrete weren't grouted properly with sufficient oscillation, air would be stuck within the acute corners of the water-cement moldboard. After demolding, irregular pores which resemble the look of a honeycomb(air voids) would rest in the corners. Therefore, the architectural circles often refer such porosity as a "honetcomb." Creating a 45degree angle at the corners may help to avoid such results.
35The interfaces are traces of grouting performed at different stages of construction.

Pic.21 The conoid walls appear as diamond-shaped lattice beams inside the chapel.
Pic.22 The surface materials applied to the external walls of the chapel are diamond-shaped glass tiles.



Pic.21

Pic.22

beams, a constrained sense of flow[36] is deliberately implemented in the chapel. The visual quality of the conoid streamline mutates according to the position of its viewer. As unique as it is, this visual flow does not exist in any other school buildings constructed in the same era.

As the construction material shifted from the original steel-wood to a reinforced concrete, the protection of the external surface was naturally a focus on its concrete exterior. Any application on the surface would have directly influenced the appearance of the architecture. The four conoid walls, which come in two pairs determines the size and proportion of the diamond-shaped lattice formed by the rib beams exposed within the chapel (Pic.21). The elegant proportion of the diamond-shaped design is also adopted as the principal ratio of the ceramic tiles on the surface of the external wall (Pic.22). Although the tiles and the lattice beams are different in size, with the same ratio, this creates an interrelation that links the interior and exterior.

The purpose of applying a surface material was to add a layer of protection on the porous concrete surface of the shells. With "waterproof"[37] being its primary function, and a complementary purpose to reflect the quality of a traditional Chinese building, a layer of glaze was adopted to the surface of the ceramic tiles. On one hand, the choice of color reflected the orange hueadopted in glass tiles paved on the roofs of important Chinese architectures[38]. On the other hand, the glazed surface was intended to achieve a water-repellent effect on the external curved surface. Along with the help of gravity, water flows down the curve without polluting the concrete surface with dusts in the rain. Water penetration can cause rebar erosion as raindrops permeate the concrete layer. However, as the ceramic tiles applied to the chapel were finished in a low fire kiln39, any slightest

36.The 45degree angle was also applied on the rectangular tiles at the corridor of the College of Arts; therefore, as pedestrians stroll along the corridor, they would also share a similar diamond-shaped visual on the pavement. This pattern applied on the pavement is apparently different from the square pavement at its hall and gateway. According to Chen, the diamond-shaped red brick tiles were designed to accentuate the movement at the corridor, which is the main route of circulation within the building. Likewise, the diamond-shaped geometric pattern inside and outside of the chapel was also designed to create the same sense of flow.

37.In regard to the function of ceramic tile, Chen explained that "the ceramic tiles on the external wall was to protect the concrete roof with its waterproof and stain resistant quality." Ref. C. K. Chen, 1963

38.C. K. Chen once mentioned that gold is the color applied on Chinese palaces. As a church serves as the dwelling temple of God, he also adopted the same golden color to the Luce Chapel. "Regarding the color…I thought of applying the colors of a traditional Chinese roof, which are usually blue, green or yellow. As the color blue and green are very much the same with the sky and trees of the surrounding environment, color replication would have resulted confusion and also absorbs a vast amount of radiant heat. On the contrary, yellow follows the traditional character of our religious buildings. Therefore, in the end we used yellow on the chapel. The diamond-shaped tiles echoes the crisscross beams inside. The tiles consist of two varieties. On every other tile, a pinpoint decoration is added to create the horizontal lines which accentuate the curvature of the walls," stated Chen. Ref. C. K. Chen, 1963

39.According to the glaze analysis conducted by Dr. Chen,Tung-Ho, an associate researcher at the National Palace Museum who joined the research project initiated by the "Keeping it Modern"Grant provided by the Getty Foundation in 2015, the ceramictiles paved on the chapel were very likely produced through a low fire kiln with a temperature of seven hundred to eight hundred Celsius, which is a lot lower than the high fire kiln used to produce regular tiles that heats up to 1200 Celsius and higher. The analysis of the remaining ceramic tiles in store shows that the color variation of the glaze was caused by the differences in fire temperature. At that time, batches of ceramic tiles were fired separately with a manual control on the firewood. Without a scientific instrument to control the fire, it was very difficult to achieve thermal consistency with primitive techniques.

Pic.23 The width of mortar in between tiles control the eccentric geometric order of the curves, and frames aesthetic beauty of the curvature (Photo by Kuo, Chi-Jeng during the execution of the granted "Keeping It Modern"conservation research project)

carelessness during its manufacturing process would have cause color variations on different batches of ceramic tiles. Nevertheless, these errors were later integrated into Chen's ingenious design concepts.[40] Chen made use of this error and created a fun twist with the handwork texture on top of the rigid scientific reasoning of the structure. Being a well-trained modernist, Chen was well aware that the uniqueness of the chapel design lays at the curves of its conoid walls. Therefore, Chen seized every opportunity to feature the beauty of the conoid curves. He also intended to create a dynamic visual to the aesthetic beauty of the curve with the viewers approach the chapel from different angles and directions. To achieve this purpose, he manufactured two types of diamond-shaped tiles: one with a smooth glazed finish, and another with a "mastoid" protrusion at the center. The idea of a "mastoid" may have derived from the traditional Hokkien wall tiles[41] made for protection clay-based rammed wall either. This tiny protrusion at the center not only is an important visual factor which highlights the beauty of the curves, but also acts as a point of alignment which contributed immensely to the accuracy of the geometric pavement (Pic.23). The dotted shades of the mastoid protrusions create dots of curves that paralleled the curves result from the concrete intervals in between the ceramic tiles. These curves complimented each other and display a rich visual sensation to the aesthetic beauty of the architecture.

Apart from mirroring the lattice beams inside the chapel, the diamond-shaped ceramic tiles are also essential for the adjustments of the mortar intervals in between the tiles on the external walls. The four conoid walls are wide at the bottom and narrow on top, therefore the size of the tiles also decreases as the building reaches high up in the air. The walls at the sides of the altar are ten meters wide at the very top with a bottom width of fifteen meters. Although the ends only bear a five-meter difference in width, thetiles used on the bottom are half twice the amount as usedon top. Therefore, Chen adjusted the mortar intervals in between the tiles accordingly to balance the pavement. All tiles are leveled according to the horizontal line of its height, the length of which is longer for levels closer to the ground, and reduces as the building grow taller. In order to keep the harmony with the smooth and elegant curve based on geometric symmetry, the number of tiles at every horizontal level is identical. To achieve this arrangement, the width of mortar interval at each horizontal level is attained by calculating the average widths (through subtracting the total width of ceramic tiles with the length of each horizontal level, then divided by the number of tiles of the level), which builds the construction precision at each interval in between tiles. Along with the "mastoid"

40.According to the editorial committee of "The Wind of Tunghai," the fortieth anniversary special edition of the university's history, during the interview C. K. Chen recalled that when the ceramictiles were delivered to the university, Mr. Wu, Ken-Tsung from the construction company ran to Chen nervously, and said, "I'm sorry! The color of the ceramictiles are inconsistent! What should we do?" This transmutation of glaze resulted color inconsistency on all the tiles. Instead of the golden yellow color ordered by Chen, these tiles comprise of a golden color that includes tinges of brown or green. However, Chen calmed Wu by telling him that this was his original intention for the inconsistency prevented a monotonous pattern.

41.Similar mastoid protrusion can be found on the gables of houses in Taiwan and mainland China. Rainy regions such as Jiangnan and Hokkien often nail wooden or metal nails on thin tiles. When these tiles are placed one on top of another, like the scales of a fish, this forms a drainage layer of construction. This technique is called "Chuan Wa Shan" in Chinese, which means "wearing a tiled shirt." Some also called it "fish scale board" for its scale-like texture. Gradually, the name clapboard siding also emerges. However, on top of the concrete exterior, Chen did not pave these tiles on top of one another like fish scales, but laid the tiles directly on the curved surface and filled the intervals in between tiles with cement. Moreover, when Chen talked about the construction methods used on the external walls, he never described his design as a transformation of "fish scale board" or the technique "Chuan Wa Shan" in any interviews or classes he lectured in the Architecture Department.

Pic.24 Through the photo record taken during the pavement construction of tiles, we can see that the tiles with mastoid were paved first as an important source of horizontal alignment before the ones without were filled in between to control the geometric pattern of the tile pavement.

tiles that contribute the horizontal alignment, the entire pavement construction followed a strict geometric order (Pic.23), which Kuang-Yuan Construction Company precisely brought to completion. To this day, people still stand in awe of their achievements, which exhibits the modern spirit to its fullness.

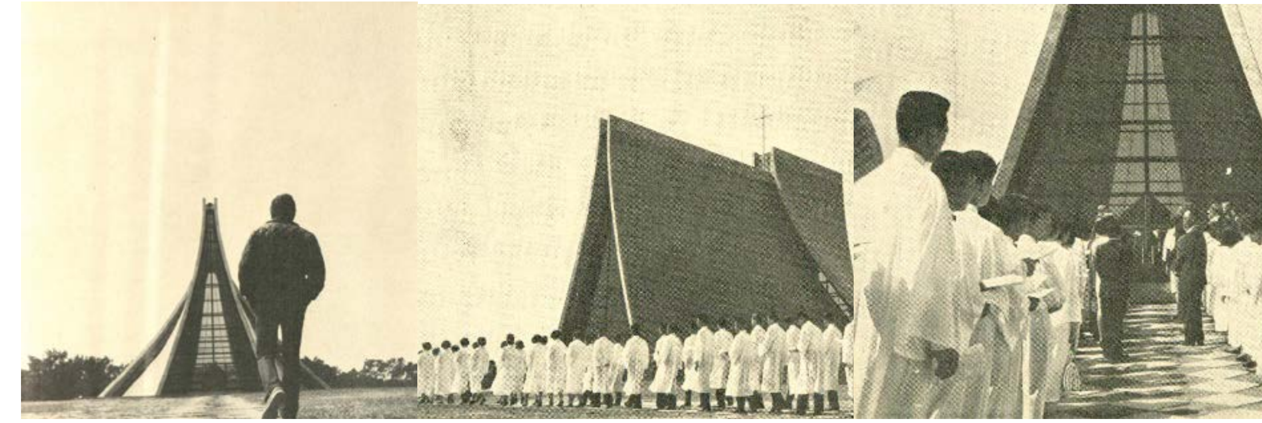
Pic.25 Looking at the Luce Chapel from the boy's dormitory area. The principal's office (the sloped rooftop at the right hand corner of the picture) is at its west. The roof of the chapel clearly occupies the center of attention at the skyline. (Photo by Chen during construction)

Responding to the Surroundings
On-site planing: Blend in the physical environmrnt

As described earlier, Chen in his initial campus planning believed that "being the spirit of the school, a chapel shall be a taller building located at the center of the campus so that people from every corner can see." This is accomplished by erecting the chapel on top the vast lawn, which lies at the intercession of circulation that leads to various sections on campus separated according to their functions. This is where the chapel lies to this very day. From the brush painting illustrated in the beginning of the design stage, the Luce Chapel has been the sole building on top of this boundless lawn. With a size relatively small for the lawn, the construction of its operational base is fairly simple without any nearby buildings in its surrounding. Firstly, Chen had to decide the orientation of this architecture built purely for a religious purpose. Then, he had to solve the problem regarding the slope.

As Chen elaborated the relationship between the chapel and its surrounding, he referred to the orientation of the chapel and the slope of the lawn, and explained that "eastward, the campus faces the Taichung Basin. The chapel sits west facing east, an orientation that enjoys the view of the spectacular mountain range afar." Since the campus of Tunghai locates on the higher ground of the basin, the slope decreases eastward. As the chapel sits on the higher west end of the slope, its worship and ceremonial functions are thus emphasized when people walk up to join the worship ceremonies at the Temple of God. Chen also made efficient use of natural lights to build up the aura of sacrosanctity. "The seating of the chapel can hold a congregation of four hundred and fifty people, which was half of the school's population. The seats lies at the east side of the chapel while the altar sits at the west end. When the morning light pierces through the eastern window during morning services, the altar would be immersed by the morning light, which shall stimulate piety and focus the attention of the congregation on divine matters."[42]The grand windows at both the east and west end of the chapel granted sufficient natural lights without resulting diffuse light. As the sun moves

42.



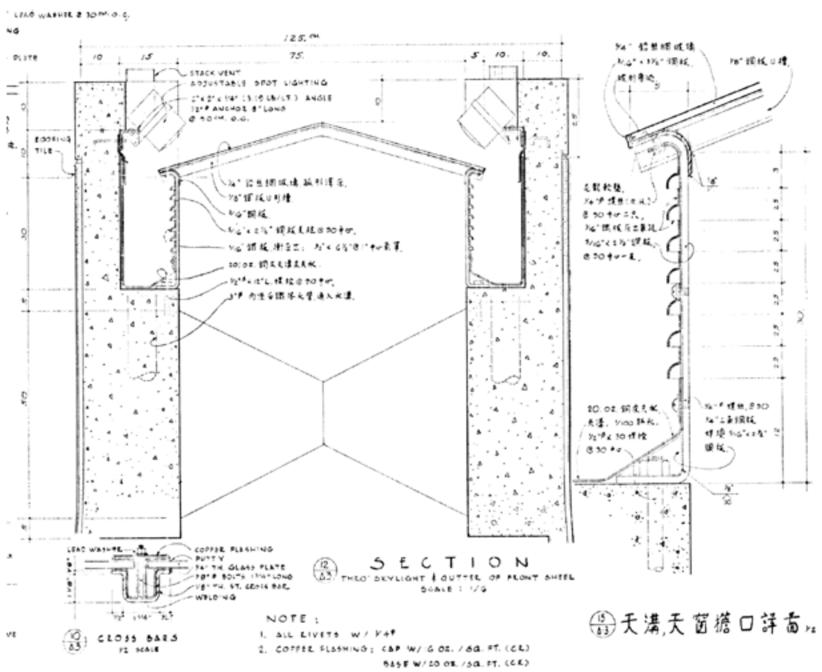
Pic. 26 When people go up to the chapel from the lower east end of the slope, they look up naturally. This visual angle serves as a prelude to the worship ceremony

Pic. 27 Leaving the chapel, the east opening leads to the green.

to the west, it also creates a dramatic influence on the shadow within the chapel. This intricate manipulation of the visual effect of natural lights on the form and structure within the chapel is a major focus of the chapel's interior design. As people enter the chapel to join in worship, this directs their concentration upwards (Pic.26). As they leave the chapel after worship, they would overlook the entire Taichung Basin, and enjoy the view of the distant Central Mountain Range (Pic.27). This meticulous arrangement of orientation, route, and visual angles adds a theatrical experience to the chapel's most essential ceremonial function, its weekly worship, and reflects the "artistic concept" Chen set out to achieve through the brush painting he set forth at the initial founding stage of the university.

As the advantage of a slope was utilized in building up the pious atmosphere of the chapel's worship function, there were other issues regarding its environmental conditions for being the only architecture erected on top an empty lawn. Situated on the Dadu Mountain, which locates between the Taichung Basin and the city's coastal plain, its relative smooth terrain without dramatic rise and fall fosters a windy environment, which was even more intensified as it lacked vegetation to add friction to its ground. Bare hills without trees, and sweet potato and sugar cane fields had once been the major landscape characteristics of Dadu Mountain before massive plantation took place. The only tall trees on the mountain were arbors, which also contributed to a notable wind shear in the environment. Both the terrain and vegetation on both sides of Dadu Mountain accentuated the harshness of its mountain wind. With this environmental condition, finding a proper orientation for the architecture was more essential than finding solutions for issues concerning wind-pressure resistance and the issue of noise and vibration. This is even more important for a building that stands as the only architecture erected twenty meters above ground level on a empty lawn. After the orientation and directions concerning its two openings were decided with the main structure inside the chapel being set as a space enclosed by four conoid walls that sits at the west faces east, the design focuses then turned toward the severe conditions of its environment, which is especially harsh in the winters.

First of all, by choosing a structure with only two openings facing east and west respectively, the chapel finds shelter from the windy surroundings as none of its four curved walls include any open windows. This avoided both the gentle south breeze during the summer and the sharp north wind in the winter. Both the south and north wind are directed upward as they hit the curves of the walls. The leeward curved walls break the rolling winds with their dynamic curvatures, which change according to its height. This minimizes the influence of wind on ground level activities, which may result in awkwardness or embarrassment when the wind lifts



Pic. 28 The section drawing of the sky windowsin the original profile samples of the Luce Chapel

the skirts of pedestrians. This principle of maintaining the east and west openings as the only two openings of the chapel have also simplified the control over the building's natural light.

As aforementioned, the acute angles on both ends of the diamond-shaped plan's longer axis were removed to form the openings of this building enclosed by four conoid walls. The windows at the front, the back and the ceiling were welded with channel steels, while translucent brown energy saving window films were attached to avoid over exposure of sunlight and light reflection. The natural light, which penetrates through the fixed glass windows on the eastward, and westward perpendicular fixed windows, which rise to more than nineteen meters above ground level,is the major source of light for day time indoor activities. Dramatic light and shadow effects are directed by the nature lights on sunny days. The connection points at the openings of the curved structure were part of the design. The RC joints on rooftop holds the building together even when thermal variations, wind, or seismic activities cause pull and drag forces between the curved surfaces. At the sides of the curved walls, curved window belts were adopted as the connection points, which absorb the same forces. It is the diamond-shaped concrete hinge joints placed to handle the forces caused by seismic activities, thermal expansion and contraction. Alongside the dynamic curvature of the lattice beams, the acclaimed "one-line sky" openings renders an interesting and yet elegant light and shadow variation which is a part of to the visual feast made up by the structure, openings, orientation, light and shadow within the chapel, and displays the aesthetics of the Luce Chapel that are celebrated by many.

All the openings of the Luce Chapel, whether it be the grand windows at the east and west ends of the chapel, the curved window belts along the sides of the curved walls, or the "lined sky windows" at the roof, draw natural lights to the interior. In addition, tempered glass was applied to the steel windows frames of all three fixed windows, which could not open. Narrow openings only exist on the steel shutters near the ceiling and the grand level. At the ground level, thin sliding glass windows, which consist of a thickness of only 3 mm, were placed alongside the shutters to prevent the whirlwind of a typhoon[43]. With a spacious interior, which holds four hundred and fifty seats at the congregational seating area, an efficient ventilation is necessary. To avoid the impression of suffocation resulting from limited openings, the construction team implemented the concept of "buoyancy ventilation." Besides the shutters facing east and west at the ground level, and the ones close to the skyline, the "lined sky windows" also has a hidden function--by utilizing the height of the horizontal window belts made of steel, the depth of the beams at the top of the roof became the parapets of the skywindows. The side gaps of the skywindows, which are indentation caused by height variation between the sky windows and its parapets, also contain the function of heat dissipation (Pic. 28). The two side gaps at both side of the sky windows created east-west aligned cooling window belt which runs through the center axis of the chapel. Along with

43.The curved belt-shaped windows connected to the curved walls are all fixed windows with shutters added to the bottom. The top of the four curved walls ends with deep beams which binds the walls together without any open windows.

the horizontal window belts at the east-west aligned ground level, the shutters at the bottom of the curved side windows, a buoyancy effectthus developed a ventilation effect similar to the one of the stack effect. When the chapel was open for indoor activities, the warmer air heated by audiences'breaths and body temperature from the congregation would rise and dissipate through the louver on the two side of the sky windows. With the front and the back doorsbeing opened, and shutter louvers below the eastward and westward windows bringing in fresh air, indoor hot air would rise as the atmospheric pressure changes when these openings ventilate the interior with the cold air from the chapel lawn. The light yellow ceramic tiles paved on the surface of the exterior has low heat absorption, therefore it is not a problem for the chapel to stand without any thermal insulation on the surface of its exterior. With a height nearly twenty meters above ground level, the building can withstand hours of solarization as indoor thermal variation enforces the stack effect, which generates ventilation. Air stagnation is avoided as the hot air rises and gets pushed through the vent on top of the chapel. With cold air constantly coming in from the chapel lawn, overheating at the seating area is thus averted.

The design, which made good use of its grand section, achieved a ideal inner thermal environment that fulfills the rational dimension of modernism whilst bringing in a splendid aesthetic beauty to the visual feast of Luce Chapel. Built in Taiwan at the beginning of 1960s, this intricate design full of rational reasoning, is a demonstration of the "zeitgeist" depicted in the Bauhaus modernism movement. In the 1960s Taiwan, air conditioning system was extremely lavish for an age of material shortage. Though the chapel had resources from the West, it still made use of the plainest physics and the natural conditions of its surrounding environment without depending on manual labor or air-conditioning machines to control its indoor environment. In fact, before the Luce Chapel installed an air-conditioning system in early 1990s, this buoyancy-driven ventilation system had operated efficiently for nearly thirty years. The fans at the parapets next to the congregational seating area would only be turned on during the hottest to provide physical comfort by increasing indoor airflow[44]. Contradicting to the high-tech performance that dominated the architectural fashion of the 1980s, the design of the Luce Chapel humbly displayed the knowledge behind its physical environment that hid within its structural system and construction techniques, and had functioned for more than a quarter of a century. Built at a time when the economy of the country was yet to be recovered, the chapel stood as an outstanding but modest interpretation of modernism in the postwar Taiwan.

While the chapel's physical condition concerning its thermal environment is set forth marvelously, the performance of its acoustic and light environment is just as splendid. The part of light environment concerning the building's artificial lighting consists of indirect lights hidden at the indentations created by the height variation at the profile of its interior. The "chandeliers" commonly seen in western chapels with greater spans was entirely omitted in the design of Luce Chapel. Since the chapel was designed at a time when church activities usually took place during day time, the illumination in the evening was mainly designed to highlight the beauty of its form as evening activities were few. Its secondary function is to light up the congregational seating area for the congregational hymn and Bible sessions. Thus, the emphasis of lighting was focused on the following five spots. Within the indentation in between the lattice beams and the congregational seating area, spotlights were installed to light up the curved surfaces from the sides of the indoor wooden parapets to accentuate the form of the diamond-shaped lattice beam. On top of the hinge joints beneath the sky windows, a spotlight was inserted to project downward above the altar to feature the diamond-shaped lattice at

44.The addition of electric fans proved that the actual ventilation rate provided by the louvers was insufficient for the country's hottest seasons. According to the on-site studies of the conservation research sponsored by the Getty Foundation in 2014, the actual structures of the sky windows did not follow the original section drawing given by I. M. Pei and Associates, which provided a design with ventilation function. Instead of the original triangular glass structure, the actual sky windows only consists of a single sheet of glass, which is fixed to the steel frame by removable screws. On the sides of the roof, the structure only retracted about 30 cm from the edges of the sky windows' glass to avoid direct raindrop, rather than adding a perpendicular surface by bending steel panels to form an indentation with vents on the shutters. Without the protection of a perpendicular surface, another layer of steel wire mesh is attached to the top of the concrete joints from the inside to prevent leaves, bugs, and birds from entering through the top. This solution points to the defoliation problem at the rooftop caused by the windiness of Dadu Mountain. Defoliation also means ponding at the gutter during rainy seasons. Now and again, water would pour in and cause steel erosion and ponding within the chapel. To solve this problem, the chaplain's office sealed the shutter in 1993; however, without ventilation, this also resulted air stagnation. Furthermore, the shutters at the bottom of the architecture were also ignored and blocked by big furniture, aggravating the problem of ventilation deficiency, which were ultimately resolved by the installation of an air conditioning system.

the top of the curved walls. Furthermore, another major indoor illumination focus directs to the altar. The design placed spotlights at the short end of the beams and projected lights to the altar and added two supplementary lights alongside the curved window belts, which consist of a height of eight meters at both the left and right hand corner. This was designed in a way to illuminate activities on the altar without blocking the view from the seating areas. Out on the roof, a spotlight lights up the cross, which shines with the moon and the stars at night. Twenty meters away from both the north and south ends of the exterior rest the outdoor spotlights, which include the same glass tiles at the surface of the lamp to retain a consistency with the chapel. The chapel was thus "visible from most corners of suburb Taichung with its night time illumination."

As for the acoustic environment, the four conoid walls, which consist of two pairs of symmetric surface enclose a negative space that constitutes a ceiling height of nearly twenty meters. This negative space is an excellent sound field for reverberation. With a reverberation time that lasts nearly three seconds, this creates a great sound field for music performances. However, this reverberation condition also means disadvantages for activities such as sermons and prayer meetings, which demands verbal articulation. During sermons, speakers would often have to speak loudly when the reverberation time causes echoes and influences verbal articulation. Nevertheless, excess volume would also amplify static noise. According to a description of Pastor Chow, Lien-hwa, the lattice beams of the hyperboloid curved walls also refines the sound effects within the chapel. With the exposed diamond-shaped rib beams made of hard concrete composite identical to the texture of the walls, the diamond-shaped lattices are capable of blocking some direct rebound to the acoustic orientation of the congregation seating area[45], reducing the sonic energy while decreasing reverberation at the same time[46]. Besides the decay of sonic energy possibly caused by the acoustic rebound resulted from the multiple angles of the lattice rib beams, the design team also introduced efficient "sound-absorbing" materials. The original chapel benches, designed to be integrally formed with millstone and concrete directly molded and fixed to a marble floor[47], were switched to wooden benches and flooring[48] to reduce rebound. The concerns regarding the building's acoustic environment were hidden in the detailed design of structural systems, construction, and angles, delivering fabulous environmental control techniques under its modern architectural aesthetics. This marvelous performance of "reasoning" behind its acoustic techniques hidesin the curve structure and its relationship with the floor, and requires detail investigation to discover indications of the astounding thoughtfulness behind the design of the chapel.

Conclusion

Founded in a time when the Chinese Civil War finally came to a close, from the very beginning of its founding stage, Tunghai University was constantly challenged by questions regarding whether and how Protestant churches should continue their mission works in the so-called "Free China" and Asia as the thirteen Christian Universities sponsored by Protestant communities were closed after the war. Should the thirteen universities be reopened in Taiwan, or should the board establish a new university solely for the purpose of educating the youths in Taiwan? Would the school focus on professional training or liberal arts? What kind of campus and campus lifestyle do the university needs to support its educational ideals? What should be the style of the school buildings? How should students and faculty members interact on campus? How should the students learn in their life on campus? Through a series of discussion and arguments, Tunghai finally found its ground with a liberal and democratic aura that celebrates the richness

45.According to C. K. Chen, "the indoor acoustic effect shall be extremely ideal. Although the curved surface consists of a hard material like concrete, the supplementary crisscrossing beams and their uneven and unparalleled surfaces prevents echoes, resonance, and polyphony along with its convex quality. Ref. Chen, 2003, pp. 190-202

46.Chow, Lien-Hwa once recalled that on the way to the inauguration ceremony, I. M. Pei asked him about the acoustic effect of the chapel, and mentioned the suicide of a New York architect who killed himself for unable to outlive the embarrassment of designing a hall with bad acoustic effects. When Chow heard the story, he did not have the courage to give any negative comments, and told him that the acoustic effect was fine. This incident shows how Pei took to heart in regard to the chapel's internal acoustic effect. However, as the chapel functions both as a place for musical performance and oral activities such as sermons and prayers, it was difficult to attend the acoustic demands of both functions under a singular space. The requirement for verbal articulation stands contradictory to the intrinsic quality of the building's acoustic environment. Therefore, it was necessary to find an alternative solution. In order to avoid the sound being focused on particular spots as the curvature of the curved wall directs rebounds, the uneven diamond-shaped lattice formed by the exposed concrete rib beams were structured to generate the acoustic quality of irregular rebound without the intervention of any devices.

47.A similar concrete structure is seen on the congregational benches within the chapel of Kung-Tung Technical Senior High School. The frames of its benches were made of grouted concrete with wooden boards attached to form the seats and the backs of the benches.

48.Ultimately, the floor from the congregational area to the altar were installed with lauan wood panels that comprised of a thickness of one inch eight points and a width of one inch two points. With a solid thickness in addition to the intrinsic flexibility of lauan, the flooring created an excellent sound absorbing effect. In 2009, the carpet above the surface of the lauan flooring was worn out. Instead of polishing and applying protective seals to the surface, the original wood floor was replaced by plywood flooring coated with wood pattern plastic finishes which consists of a thickness of six points only. With the thickness being five points thinner than the original flooring, performers who are familiar to the chapel's acoustic environment gave a feedback regarding the decline of the chapel's sound quality after a series of Christmas concerts that year.

and variety of diversity. The university chapel formed under the school's unique founding process is also very different from the ones built in the church universities in China. In the early 1960s, Peyton G. Craighill, commented on the Luce Chapel upon its completion, stating that:"Words cannot describe what the architecture has accomplished. Clearly, it reflects the highest ideal of a contemporary church building. Webelieved that the most comprehensive definition for…the Luce Chapel should be a church instead of a chapel."This is also the definition Tunghai wished to explore as the school conducted the research regarding the historical background of the chapel with funds provided by the Getty Foundation.

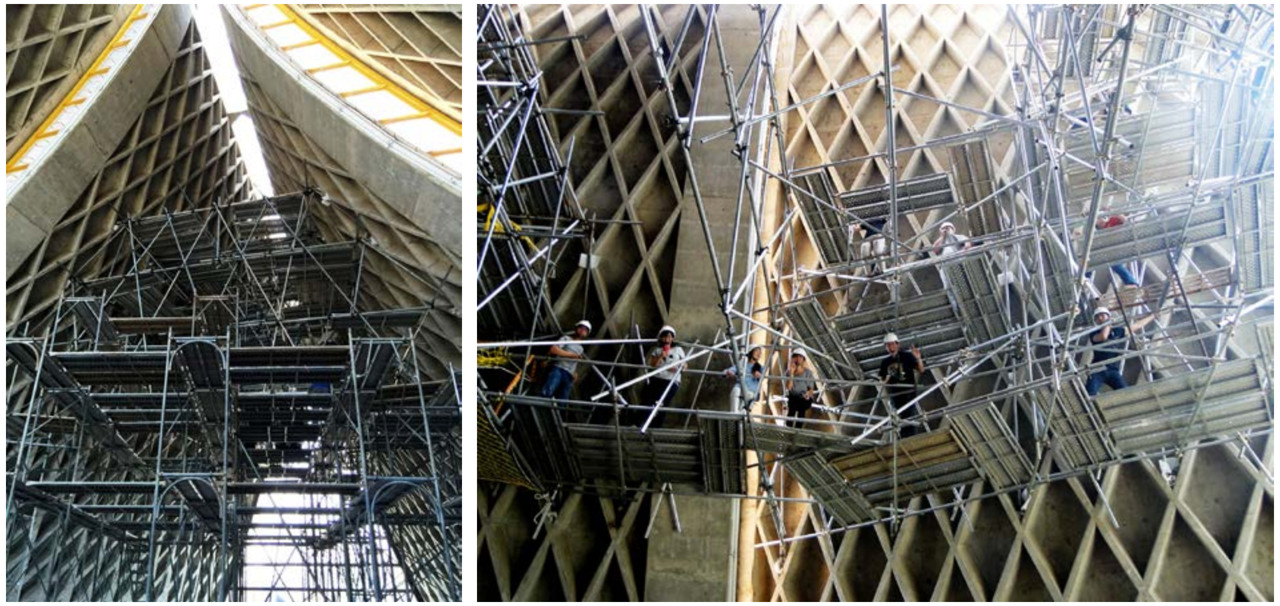
In the past, the researches on the Luce Chapel were mainly focused on its significance as a modern architecture built in postwar Taiwan. This includes discussions concerning aspects such as its modern abstractive interpretation of the Chinese aesthetic concept, the development of contemporary church arctitectures, the representationby churches to Taiwan's postwar modern architecture, the development of the fair-faced concrete technique in Taiwan, and the elaboration on the constitution and physics behind the chapel's shell structure. In comparison to its architectural structure, studies regarding the history of the development and construction of the chapel are rare. This shows that most of the existing researches have focused their elaboration on the cultural value of the chapel. Investigation and studies concerning the conservation of the chapel was never thorough; therefore, discussions on the design intention which aimed to display the experimental spirit within the higher educational ideals set in the founding stage of the school is also neglected along with the preservation and maintenance of its original forms.

In fact, although the United Board of Christian Higher Education in Asia meant to establish a new Christian university in what was known as the "Free China," the construction budget of the Luce Chapel came from the Luce family, who gave their full financial support in the early 1960s. Overall, the construction of the entire campus of Tunghai was highly experimental. It took a sufficient budget, and an independent design and construction team to fulfill the experiments. As the United Board slowly withdrew its financial support, the university had to face the challenge of independence financially. After mid1970s, the university was forced to contract out its maintenance and construction of its school buildings to the cheapest outsource, or simply replace the worn-out facilities with new models due to its much-limited budget . This was the method applied to the maintenance of all school buildings including the Luce Chapel. Actually, choosing the cheapest outsource had a lot of side effects. Ultimately, the school ended up spending more to keep the public image regarding the authenticity of the Luce Chapel.[50]

In Fall 2014, the chapel was luckily listed as one of the first ten modern buildings chosen to receive the "Keep it Modern" Grant from the Getty Foundation to activate a thorough investigative research on the conservation of the Luce Chapel concerning studies in regards to the investigation, repair, and reuse of its materials (Pic.29). Being granted the award not only reaffirms the chapel's value as a classic modern architecture, but also reminds the school and the country of the chapel's distinctive significance. To Taiwan, the Grant witnesses the impact of modernism in architecture, which swept the globe in the middle of twentieth century from the West to the East. Located in the Far East, Taiwan had a chance to respond to this world trend with a unique interpretation by making a classic spatial experiment worthy of maintenance. This Grant has awaken the society's attention toward the modern architecture in Taiwan, and has turned the government's focus of cultural heritage from historical buildings and landscape built during the Qing Dynasty and the Japanese colonial period, to the architectural historical development after 1945, which is the year World War II ended. This is a significant breakthrough. For Tunghai University, the Grant has reminded the university's administration and

49For instance, when the church purchased the organ in 1992, the speakers were installed directly on top of the wooden screen at the background of the altar, and changed the flat surface of the original wooden screen to a V-shaped screen. After the Jiji earthquake in 1999, many sections of the concrete walls show cracks. The general office simply entrusted a company to fill up the cracks with non-shrinking concrete. In 2009, when alumni pointed out the worn-out floor within the chapel, the general office abandoned the solution of polishing and sealing the original wooden floor and directly replaced the original thick wood flooring with a wooden pattern plastic flooring.

50For example, when the chapel suffered from leakage at the roof, a flat sheet of glass was directly added to the original glass rooftop with silicone sealing the both ends of the wall. This resulted stains on the concrete surface, which eventually had to contract out the cleaning of the external wall to a contract cleaner, who cleaned the wall with acid liquids, which damaged the glaze on top of the ceramic glass tiles. In the same year, the chapel installed its air-conditioning system, which was also contracted out to the cheapest contractor, who used the cheapest model which cools the interior with a water cooling compressor that brings in cold waters to the ventilation ducts. This not only caused problem of booming mechanic noise which lasts to this very day, the water from the cooling tower next to the water cooling compressor also rusted all the steel window frame at the bottom of the west window. In the future, church members and alumni probably won't accept the replacement of a cheap aluminum window frame, which can be easily maintained. However, if the original steel window frame i to be restored, the rusted steel would have to be cut off and replaced entirely as it is impossible to restore the steel through rust removal. This will be a costly construction.



Pic.29 During the conservation research period, the research set up the scaffolding for a thorough inspection of the shell structure and steel frames and glasses. The scaffolds was standingon the lattice beam 8 meter height and above in order to keep the weekly activities taking place as usual.

policy making departments of the honor of owning an architecture with significant cultural values, and granted the Luce Chapel an opportunity to be set apart from the maintenance regulation of its ordinary campus building, and have a proper repair and maintenance standard. Moreover, this Grant also has impact on the conservation of cultural heritages in Taiwan. People from the school's faculty and student members, alumni, to those working in this field were inspired by the conservation research project, and intend to initiate a movement that directs to the conservation of other distinctive architectures built around the same campus at the same era.

Initiated by the Granted award from Getty Foundation which prompted to conduct a thorough conservation research on the Luce Chapel, this chapter aims to review the chapel through elaborating the development of its spatial formation and the spatial experiences within the chapel. In addition to the accounts of the chapel stated by C. K. Chen and I. M. Pei after the completion of the architecture, the purpose of the inspection is to restore the original concept of the Luce Chapel, and discover a reinterpretation fitting for the current cultural and natural environment. Before the execution of the "Keeping it Modern" project, the project team already held authentic records concerning the conditions of the chapel from 2014 to 2015. As the project began, the team has dug into the archives of the general affair office and the chaplain's office to review the repair history of the chapel diachronically, and has pondered synchronically on the motives and reasoningbehind all the treatments through studying the structure, form, acoustic environment, illumination, thermal environment, and air conditioning of the chapel. This was done in hope to find the "permanent treatments," most logical and appropriate for the renovation and maintenance of the chapel, instead of clinging to the "temporary solutions." Furthermore, as the project team reaffirms the original design concepts of C. K. Chen, it also wishes that future renovation would pay respect and attention to the intrinsic aesthetics of the chapel, and judge the necessary intervention and method of conservation through consulting experts, scholars, and consultant teams, so that future renovation and maintenance

can be based on the prerequisite of keeping the overall historical and material originality of the chapel. Tunghai University has already filed for an approval to list the Luce Chapel as a "national monument," which is the highest level within Taiwan's cultural heritage conservation, in hope of sustaining this millstone of modern architecture in Taiwan, and keep on "conversing with the world with a base stationed in Taichung."

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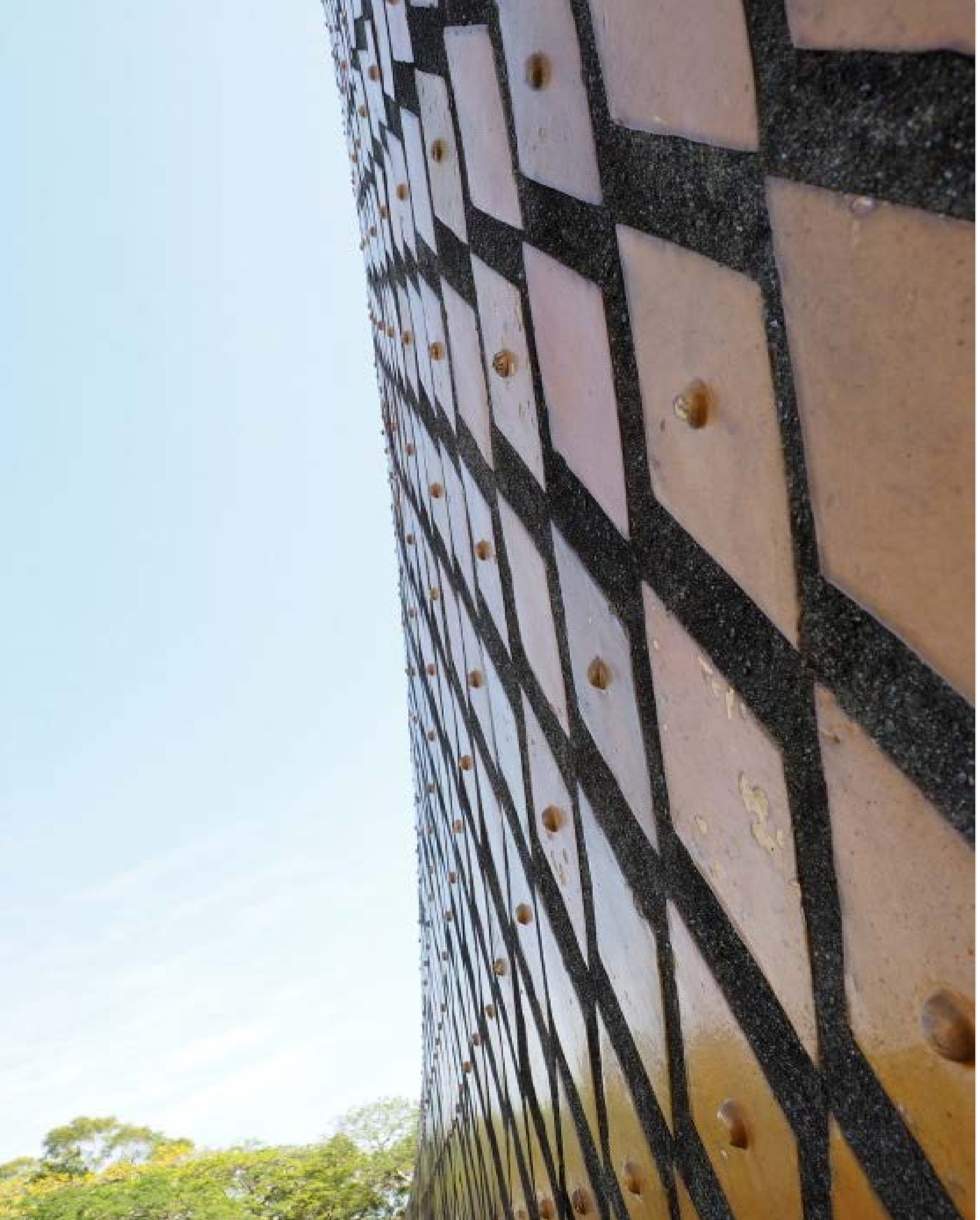


1.

Future Use Plans of Luce Chapel

Background

Luce Chapel has stood on the soil of Tunghai University for 52 years now. Ever since its completion in November 1963, it stands a symbol of the soul and the educational ideal of THU.

In 1955 when this Christian university was founded, it situated on Da Du mountain surrounded by miles and miles of green hills and farmland and there was no church to be found nearby. Therefore Tunghai Christian faculty-a lot of them were missionaries-and Christian students managed to have Sunday worship services on campus. The space of student cafeteria, school storage building, the Oberlin Center …all at some time was used for worship and served other church functions. After 1963 with the establishment of Luce Chapel, faculty and students gathered at Luce Chapel for worships and various Christian activities. A intrinsic church body became an organized local church.

University Chapel Hour was one of the long hailed traditions for Christian liberal arts colleges/universities. Following that good tradition, after the building of Luce Chapel in 1963, for many years in the Chapel we held weekly Chapel Hour and daily Evening Devotions for faculty and students. Every day the bell beaconed the whole campus—from 1963-1972 the whole campus consisted of about 100 faculty and 800 students. The strong spiritual ethos permeates the whole campus inside and out, in classrooms and extracurricular activities.

As time changes, faculty and student body increase from 800 to 8000 in the 1980s, religious life on campus became more diversified. In the 80s, with 20 percentage Christian faculty and 3 percentage Christian students, Luce Chapel, though remained a significant and unique building on Campus, only a small portion of the faculty and students will come into Luce Chapel, attending Chapel time/ services. For the majority of the students, they rarely think of the Chapel as an intrinsic part of their university life. There was no immediate need for them to come into the Chapel. We stipulate that to make Luce Chapel more approachable to the students, since 1980s, besides religious activities, concerts, dances, art performance sometimes were performed in the Chapel. It becomes a tradition for Tunghai esteemed Music Department to have their annual orchestra concert in Luce Chapel every year.

Luce Chapel is a great asset to our university. It is a well-known architectural icon, and enjoys esteemed status/reputation both nationally and internationally. More importantly, it stands at the center of Tunghai campus, by its mere existence, it strengthens the identity and contributes to the unique mission of THU as a Christian high education institute. It requires our non-ceasing efforts and creativity to make Luce Chapel relevant to the university life, building bridges between religion and living, faith and study, meditation and work. Faculty and students may approach the Chapel in its religious services, in its holy liturgy, in its ceremonial practices, or in other kind of meaningful activities held in the Chapel. By doing so, Luce Chapel then becomes an organic space and opens up channels for the holy and the mundane. A variety of activities are conducted inside and out of Luce Chapel at Christmas season and Easter season. From 2009 up to this year, the culmination of freshmen orientation is the last night when 3000 freshmen gathered around Luce Chapel and were initiated into their university life. Every year in June, department after department held their graduation ceremonies in prayer and praises, in encouragements and blessings at Luce Chapel, they embark on a new journey. Important school events such as THU Outstanding Teachers Award Presentation, Honor students Award ceremony are also conducted in Luce Chapel. In 2015, different activities held in LUCE CHAPEL can be tabulated as the following: A) Religious Activities 42%, B)Seasonal Celebration events22%, C)Weddings/Funerals10%, D)Guest visitation open house22%, E)Academic or Students related Affairs3%.

Future Use

In the near future, facing the ever increasing demand of tourists and on the other hand considering its holy aspect/religious functions, we would improve our present practices by adding the following projects:

Scheduled tour/ guided visit—different visitors have different interests—historical, architectural, Christian faith-related interests, and aesthetics, and so on. All these call for training people and providing them with different skills & knowledges to arrange for guided tour, film presentation, or worship experiences, to show people the physical beauty of Luce Chapel and its more intangible aesthetic quality.

Scheduled open time for prayers—As the spiritual center of the university, Luce Chapel should be opened daily for faculty, students and community people to come and spend some time before God in prayers/ meditations. Aided by music, bible scriptures, we hope to help people finding peace/comfort in their innermost being/souls. As Jesus once said: "Come unto me, all ye that labour and are heavy laden, and I will give you rest."

Weekly University Chapel Hour –Christians on THU campus came together and formed a church body even before the establishment of Luce Chapel. Ever since, the church offers services to the university community and the neighboring community. However, since the function of"chapel hour" and "church gathering" are different, we will endeavor to revive the good practice of "chapel hour," in the hope that the whole campus-- non-Christian faculty and students with Christians, and Christian of different church affiliations-- would come together despite our differences and pay homage to God.

After the 2015 Luce Chapel Conservation Research Project funded by the Getty Foundation, we plan to form a task force at the university level to continue finding funding and overseeing the following improvement/renovation projects in the 7 areas identified in the research. All these effort is to ensure Luce Chapel standing as an ever inspiring monuments, that more people and future generations can appreciate its uniqueness, and the love, the faith, and the hope this university was founded on.

2. Construction Investigation, Conservation and Restoration of Henry Luce Memorial Chapel: On Tiles, Foundation, Mortar, and Openings

Preface

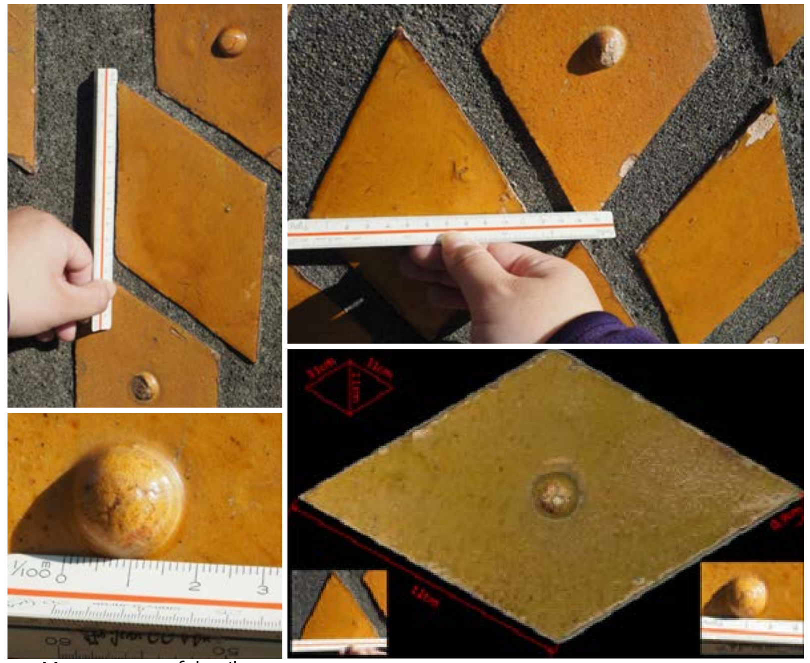
This section of the chapter aims to examine and elaborate the following construction details of Henry Luce Memorial Chapel: (1) exposed finishes (tiles and mortar), (2) foundation, (3) openings, and (4) interior floor.

We propose the following conservation themes and outline regarding the above-mentioned construction sections. First of all, we suggest a thorough identification and evaluation on the cultural value of each constructional section. This is the foundation of cultural asset preservation and conservation. This follows the important task of investigating and filing the current condition of the structure. Above all, a deterioration inspection is most urgent. This directly impacts the conservation strategy of this cultural asset. After a preliminary inspection, restoration proposal was brought forth in this section of the chapter.

The conservation research and preservation thesis of Henry Luce Chapel involve international general principles on world heritage preservation, such as the Nara Document on Authenticity 1994 and the Burra Charter 1999. Considering the essence of the above documents, a restoration proposal consists of more than one singular solution will be introduced to cover different involvement levels on non-intervention, maintenance, stabilization, repair, and restoration.

2.1 Surface texture and scale—
The rhombic tile with mastoid protrusion (front)

2.2 Surface quality and scale—
The flat rhombic tile (front)



2.3 Measurement of the tiles

Framework proposal on the exterior wall tiles and mortar

1. Assessment on the value of the tiles and mortar as parts of the cultural heritage

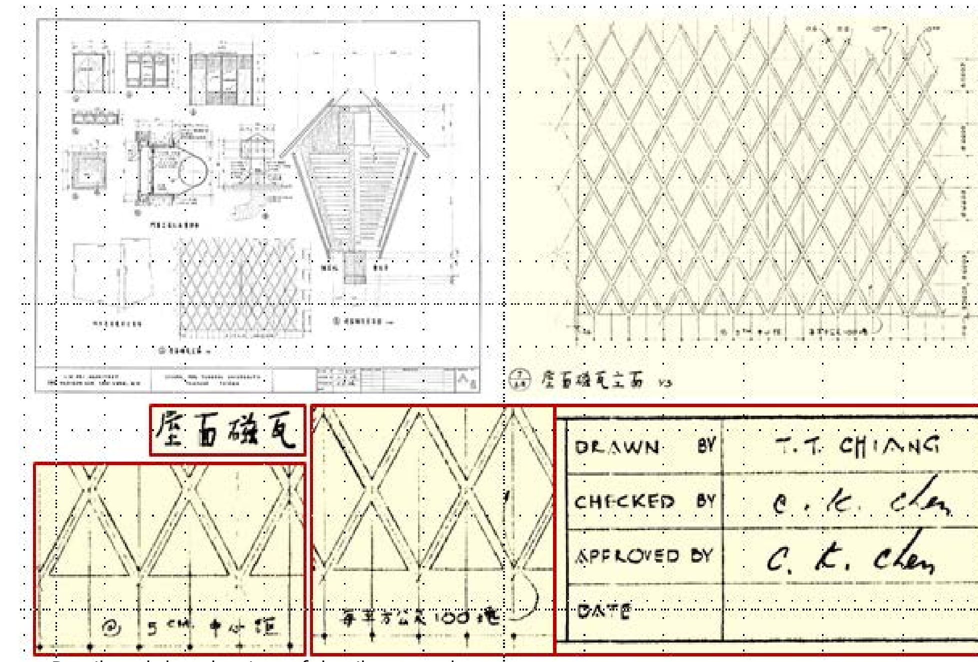
The inner grillage girder combined with the external rhombic tiles forms and constructs the structural floatation of this sanctuary. The diagonals of the outdoor tiles are proportional to the indoor lattice beam. There is a strong in-depth spatial dialogue between the exterior and interior part of the chapel in terms of color, texture, and luster. For instance, the interior space kept concrete as its exposed surface while the exterior has decorated the walls with glossy yellow rhombic tiles.

The aim of this restoration is to preserve and manifest the aesthetic and historic value of Henry Luce Memorial Chapel. It is based on the respect toward original construction materials and historical documents.[1] Base on these intentions, we compared the chapel's current construction condition with historical documents, such as the original manuscripts, design and hop drawings, interviews, and the recollection of Chen Chi-Kwan (C. K. Chen, 1921~2007). This helped us in appreciating and understanding the design concepts of Mr. C.K. Chen and the process of how each detail idea came to life. Furthermore, we will present relevant conservation issues such as the durability and authenticity of the construction materials.

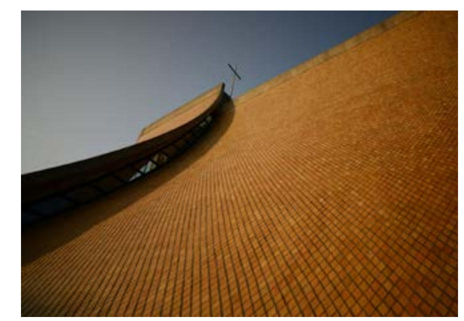
An overview on the tile paving plan—
Shape, size, material, spacing and alignment

The roofing tiles of Henry Luce Memorial Chapel, designed by Mr. C.K. Chen (Fig. 2.1~ 2.4), are the most important and basic modules of the exterior construction

1. According to "The Venice Charter" article 9. The Venice Charter for the Conservation and Restoration of Monuments and Sites is a code of professional standards that gives an international framework for the conservation and restoration of ancient buildings. The committee aims to provide principle guidelines for the preservation of historic buildings.



2.4 Details and shop drawings of the tiles, owned and collected by Tunghai University



2.5 Part of the exterior wall

2.6 Part of the external wall

materials. These tiles are consistent in shape and size. The side lengths of the rhombus are 11centimeter, and the thickness is about 0.9 centimeter (Fig. 2.1~2.3). There are two types of rhombic tiles; one with a mastoid protrusion at the center of the tile, and another with a flat surface (Fig. 2.1~2.2).

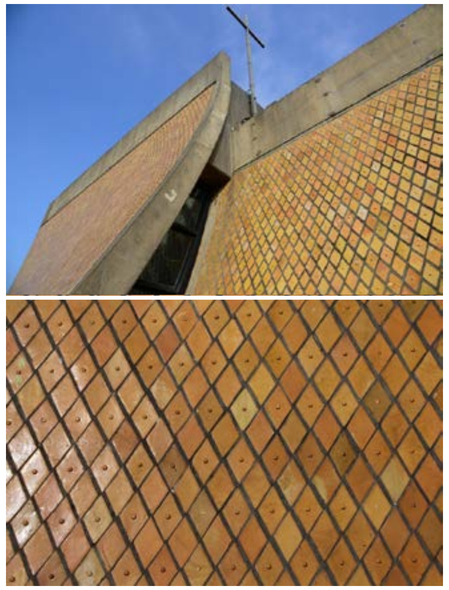
According to the instructions of the construction plan, "100 tiles should be paved per square meter, and the center of the tiles spaced out by 5 centimeters." This indicates the spacing rule and basic para-position regulation of the tiles (Fig. 1.5). Though the length of the horizontal lines at each altitude differs, the amount of the rhombic tiles on each row are the same.

Construction condition and quality control

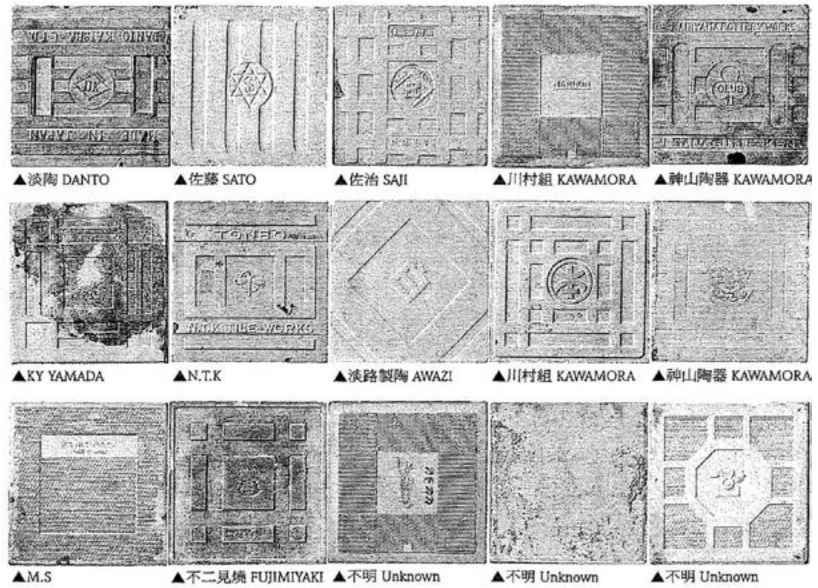
Even with clear visual instructions, the constructors had to adjust the tiling positions while paving the tiles on the curved roof. The center of the tiles had to first be identified, then turned slightly to fit the curved roof.

The size and shape of the tiles are fixed. Therefore, controlling the mortar interval between the tiles is another important tiling task. The mortar interval between the tiles has to increase as the slope of the wall decreases for the number of tiles to remain consistent on each row. Mr. C.K. Chen once mentioned, "From the side of the chapel, lines of the rows look as if they are straight lines. However, they are definitely curved lines meandering from the bottom to the top of the chapel when you observe them from the bottom of the external walls. The exterior rhombic tiles echo the indoor lattice beam. This preciseness of the mortar interval construction came from the dedication of two master workers from Guang-Yuan Construction Firm, Chi Chin-Kun and Chen Hsin-Teng, who both graduated form Industrial High School during the Japanese colonial period."

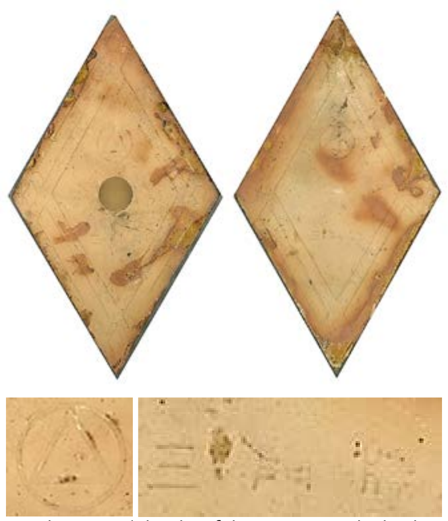
Truly, the curved roof full of rhombic tiles indicates the limit of moldboard construction. According to the picture (Fig 2.6), several undulations were observed at a distance. Mr. C.K. Chen once made an optimistic comment on the "flaw," indicating the undulations look like "God's thatched cottage worn out in years of disrepair.



2.7 Parts of the exterior wall



1.8 Tiles used on private houses in Taiwan during the Japanese colonial period(from Taisho to pre-war Showa)(Professor Horigome Jenji，2001.09)



1.9 Shapes and depths of the grooves in the back of the tiles—
Rhombic tiles (back): the mark of "Yingge" (the city of ceramics), the "Triangle" trademark, and other graphics

The original kilning quality of the tiles

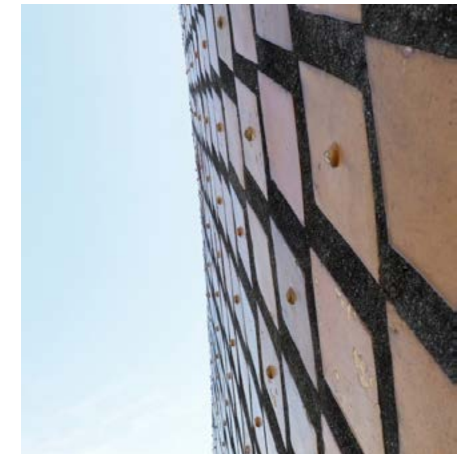
In addition to the comparison between the tiling plan of the exterior tiles and the overall construction condition, a notable difference between the original design and actual manufacture also contributes to the chapel's rich variation in color and luster. In the beginning, Mr. C.K. Chen set up the color of tiles to be pure yellow. However, the intrinsic quality of the glaze might have caused the variation of the color after kilning," said Chen. "The person in charge of Guang-Yuan construction firm, Wu Ken-Tsung apologized for the color inconsistency of the tiles, which is somewhat golden, brownish and greenish instead of the original pure golden design. However, I was very happy with the surprise, and instructed the master workers to place these tiles in a way that the colors are staggered. This would avoid a mechanical color tune, and the result is just what we hoped for." The unanticipated phenomenon of glazed color variation is called "furnace transmutation".[2] (Fig. 2.7)

The Messages behind the tile-wore walls

In order to distinguish one manufacturer's tiles from the others, most producers would stamp their trademark on the back of their tiles. Besides, grooves on the back of the tiles also increase adhesiveness. Each manufacturer has its own pattern for the grooves. Thus these grooves also serve as brand marks, providing clues on the manufacture company of the tiles. One of the most well known examples in Taiwan is the manufacture of the tiles used on private houses during the Japanese colonial period (from Taisho to pre-war Showa) (Fig. 2.8)

The tiles of Henry Luce Memorial Chapel also carry the same message. However, the marks of "Yingge" (the city of ceramics), "Triangle" trademark, and other graphics (Fig. 1.9) are rarely seen in existing records. "The making of these tiles did not use ready-made, maturely developed construction materials. They were customized for the making of the tiles of the chapel by the factories in Zhunan Township, Miaoli County, Taiwan(R.O.C.) under the commission of Wu Ken-Tsung, the owner of Guang-Yuan construction firm. Information and knowledge regarding substances of kaolin clay, raw glaze and other ingredients, manufacture origin, and kilning techniques (such as charring in stalls, tint, mix proportion) are still unknown. Having the mark of "Yingge," the authenticity on the manufacture and technician being in Zhunan is also questionable. All these mysteries require further research.

2. As above.



2.10 Parti of the exterior wall

2.12 The tile-wore wall of Zheng's Ancestral Shrine in Guanxi Township, Hsinchu County 306, Taiwan (R.O.C.) (Photo by blogger "j Adama Shih, 319 Travel Rechord")

2.13 Town house Qionglin Township, Hsinchu County 307, Taiwan (R.O.C.) (Photo by Cyonglin Cultural Workshop ：http://www.cyonglin.idv.tw/)

2.11 The tile-wore wall of Shuang-Tang House, Xinpu Township, Hsinchu County 305, Taiwan (R.O.C.) (Photo by blogger "Janice life"：http://janicelife.pixnet.net/blog/post)

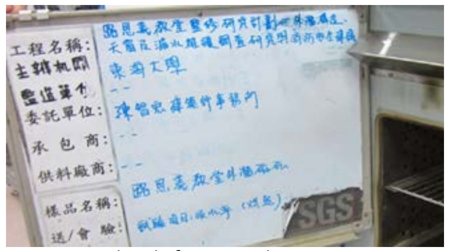
3. As above.

Image links with tile-wore wall

We can comprehend the geometry of the four conoid (saddle-shaped) shell walls from the regular patterns of the exterior tiles. The horizontal rows maintain leveled lines as the curve soars into the sky. The rhombic tiles with the mastoid paved on every other row emphasize the logic and rules of this constructional detail (Fig. 1.10). Mr. C.K. Chen mentioned, "I once suggested the principal to keep the glazed tiles in storage as gifts for guests of honor instead of using them for reconstruction. Putting the tiles in brocade boxes makes memorable gifts. The mastoid on the tiles can also be found on adobe walls of vernacular architecture in Taiwan and China. The purpose of adding mastoids is to accentuate the curving structure."[3] (Fig. 2.11~2.13).

The above gable wall is commonly seen in the adobe walls of Taiwan Hakka traditional vernacular architecture (Fig. 1. 11~1.13). The tiles of the tile-wore walls are tiered on adobe walls. There square tiles and tiles in the shape of fish scale. The walls with layers of fish scale tiles are also called fish scale walls. Each tile is fixed with a bamboo or iron nail. From afar, the wall look as if it is wearing a cloth made of tiles. Therefore the Chinese calls this type of wall a "tile-wore wall". There are two main purposes of tiling. Not only do tiles protect the adobe wall from the sun and rain, they are also great decorative embellishments.

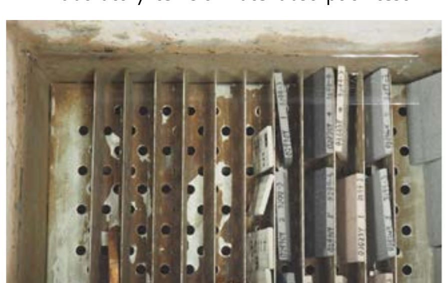
2.15 Testing one of the tiles on its water absorption: soak the tile in water after thoroughly drying the tile to test its water absorbing ability



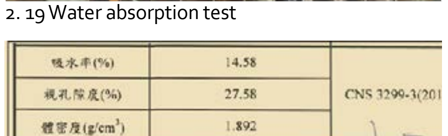
2.16 Drying the tile for water absorption test

2. 17 Laboratory items of water absorption test.

2. 18 Laboratory items of water absorption test

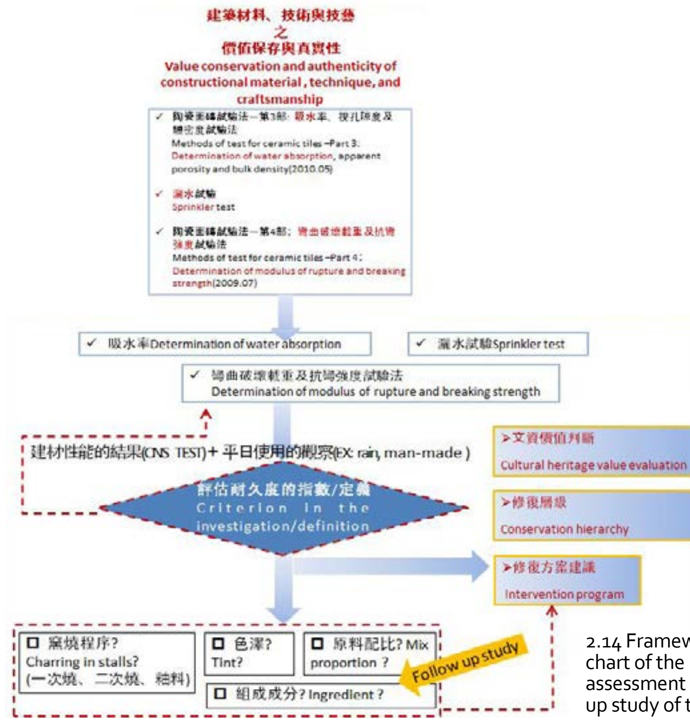


2. 19 Water absorption test



吸水率(%)	14.58	CNS 3299-3(201
視孔隙度(%)	27.58	
體密度(g/cm³)	1.892	

2. 20 Data record of water absorption test (Tested by SGS (Société Générale de Surveillance, Taiwan).



2.14 Framework and flow chart of the purpose, data assessment and follow-up study of the tiles

2. The conservation value and authenticity of construction materials, techniques, and craftsmanship

The investigation purpose, data assessment and follow-up study on the ceramic tiles

Besides the above-mentioned connection between the rhombic tile roof of Henry Luce Memorial Chapel and traditional Chinese vernacular architecture, Mr. C.K. Chen also pointed out his original intention for choosing a tiled roof. "Initially, I thoug ht of glazed tile for its waterproof function. It gives cement a coat of protection, preventing the inner reinforced concrete from rusting…," said Chen. With this design concept in mind, two questions were brought out during the research process, and three subsequent experiments followed.

Question 1: How well do the tiles protect the reinforced concrete from rainwater?

Question 2: How is the durability of glazed tile roof? This followed experiments on (1) water absorption, (2) Sprinkler test and (3) modulus of rupture and tensile strength (Fig. 2.14).

Test on water absorption

I. We chose CNS 3299-3(2010) as the test methods for ceramic tiles in section 3 of R3071-3, which lined out the experiment procedure of water absorption, apparent porosity and bulk density (2010.05) (Fig. 2.15~2.19). CNS 3299-3(2010). The methods of R3071-3 are equivalent to the ones in ISO 10545-3:1995.

Tiles were thoroughly dried before being immersed in water, and then boiled and placed in vacuum cabinet to fill the pores with water to test absorption.

II. Test results:

i. Absorption rate (Boiling method) :

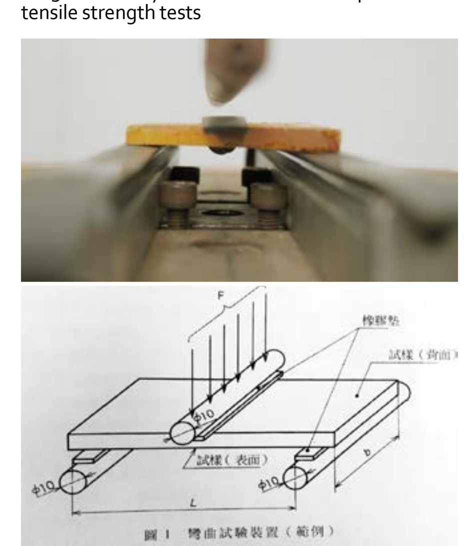
Eb (%) = [(m2b - m1) / m1] X100=14.58% (Fig. 2. 20).

依吸水率之區分	吸水率
Porcelain Ⅰa類	0.5以下
Porcelain Ⅰb類	超過0.5，3.0以下
Stone Ⅱ類	10.0以下
Earth Ware Ⅲ類	50.0以下

2.21 Data analysis on the water absorption of tiles. Reference: CNS9737 (the amended version of 2013.09.30)

2. 22 Methods of test for tiles: Sprinkler test

2. 23 Laboratory items of modulus of rupture and tensile strength tests



2. 24 The principles of modulus of rupture and tensile strength tests

ii. Similar architectural material : ceramic tiles;

10.0 < 14.58 < 50 (Fig. 2. 21)

iii. Conclusion : weak impermeability / permeable; highly decorative / strong aesthetics

The Sprinkler test

I. Condition settings (Fig. 2.22)

i. Test day: Sprinkle the tiles for a day (09:00~12:00 ; 14:00~15:00). Observe and record the next day

ii. 1.5HRS/per side/sprinkled on all four walls

iii. Water velocity: similar to the flow of average hand washing sinks

iv. Avoiding the skylight window

II. Result:

i. Inner wall: No leakage.

ii. Indoor basement: Constant leakage

Tests on the modulus of rupture and tensile strength of the ceramic tiles

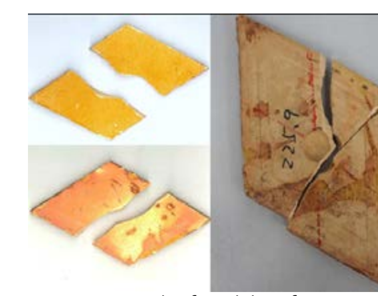
I. We chose CNS 3299-4(2009)-R3071-4 as the methods of the tests on modulus of rupture and breaking strength (Fig. 1. 23~1.26). The test method of CNS 3299-4(2009)-R3071-4 is equivalent to ISO 10545-4:1994.

II. Result:

i. N : 467 ◦ (Fig. 2.27)

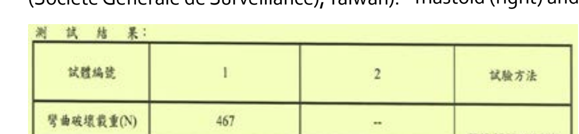
ii. Correspondent modern architectural material (Fig. 2.28): Interior wall tiles or interior wall mosaic tile ◦ 180<N=467<540; N=467 < 720 (Exterior wall tile).

iii. Conclusion: Highly decorative/strong in aesthetics



1. 25 Test records of modulus of rupture and tensile strength of the tiles (Tested by SGS (Société Générale de Surveillance), Taiwan).

2. 26 Records of modulus of rupture and tensile strength tests— on rhombic tile with the mastoid (right) and flat tile (left)



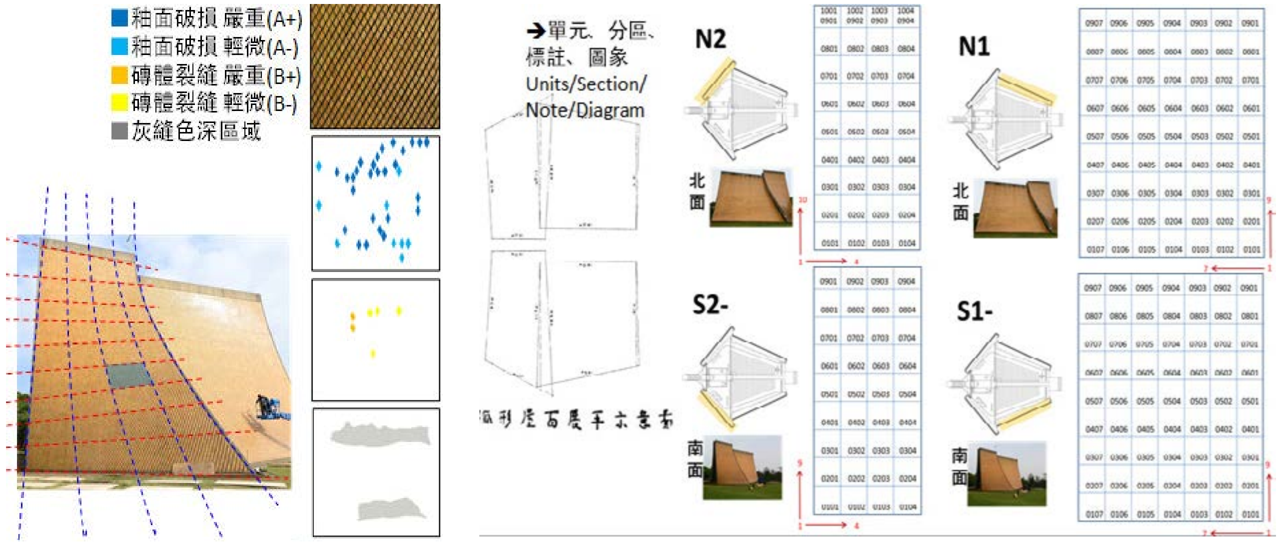
測試結果：

試體編號	1	2	試驗方法
彎曲破壞載重(N)	467	--	CNS 3299-4(2009)

2. 27 Data records of modulus of rupture and tensile strength tests (Tested by SGS (Société Générale de Surveillance) Taiwan)

	依主要用途之區分	彎曲破壞載重
Interior wall tile	內裝壁磚	108以上
Interior wall mosaic tile	內裝馬賽克壁磚	
Interior floor tile	內裝地磚	540以上
Interior floor mosaic tile	內裝馬賽克地磚	
Exterior wall tile	外裝壁磚	720以上
Exterior wall mosaic tile	外裝馬賽克壁磚	540以上
Exterior floor tile	外裝地磚	1,080以上
Exterior floor mosaic tile	外裝馬賽克地磚	540以上
mosaic tile	馬賽克面磚	540以上

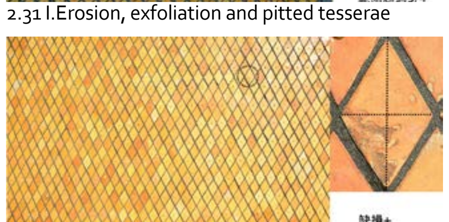
2. 28 Analysis of data of determination of modulus of rupture and breaking strength of tiles, compared with CNS9737 (before 2013.09.30 amended)



2.29 Site investigation approach and methodology of tiles and mortar


2.30 Tiles having apparent defects due to manufacturing flaws were excluded in the damage records


2.31 I.Erosion, exfoliation and pitted tesserae


2.32 Erosion, exfoliation and pitted tesserae


2.33 Erosion, exfoliation and pitted tesserae

3. Site investigation on tiles and mortar deterioration

Investigation approach and methodology of tiles and mortar

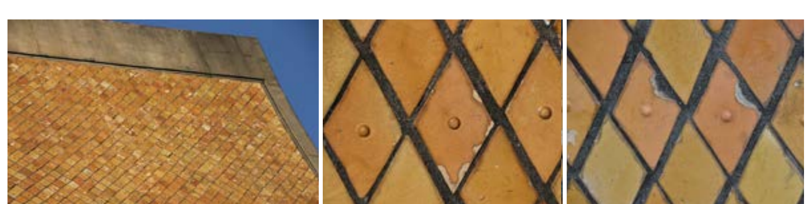
In this case, we adopt a damage atlas method to establish a primary archive for the tile and mortar deterioration investigation. The notation includes units, sections, notes, and diagrams (Fig. 2.29).

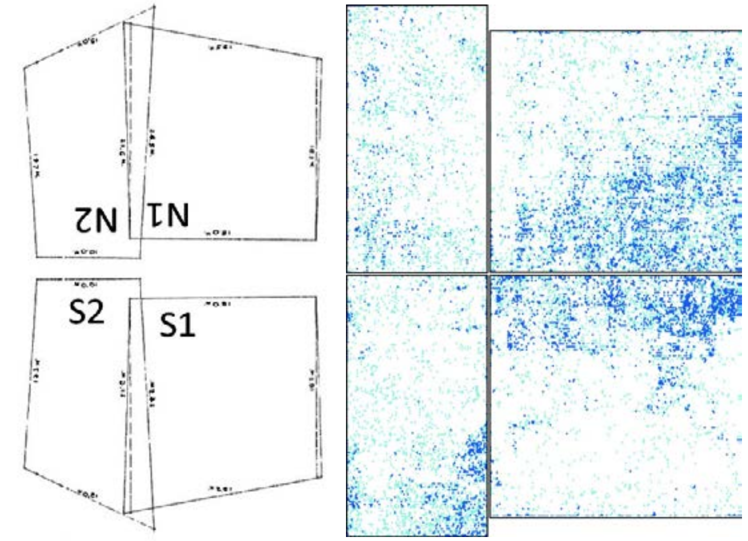
Tiles with apparent defects caused by manufacturing flaws, such as furnace transmutation defects, or faulty products, were excluded in the damage records (Fig. 2.30). For example:

I. Hidden cracks: Hairline cracks paralleled to the kiln. This type of cracks happens when the tiles are being taken out of the kiln. The cracks take place without any early warnings.

II. Chips: This happens when the clay is too dry or when the pieces collide.

III. Cooling cracks, hard cracking, lack of heat, calcification, defects in color and luster, etc.

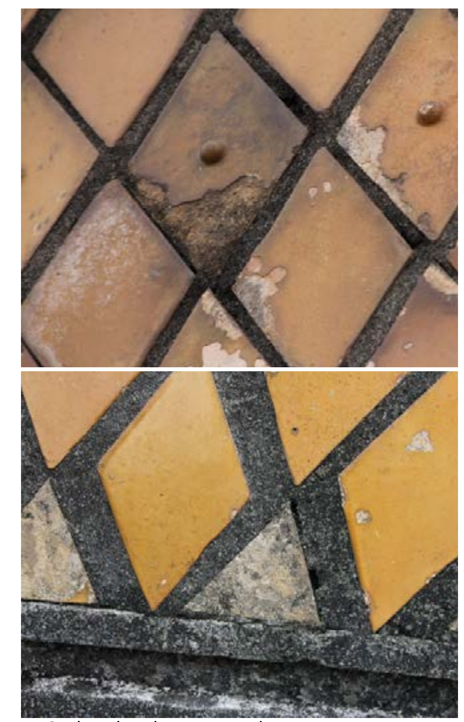

2.34 Erosion, exfoliation and pitted tesserae

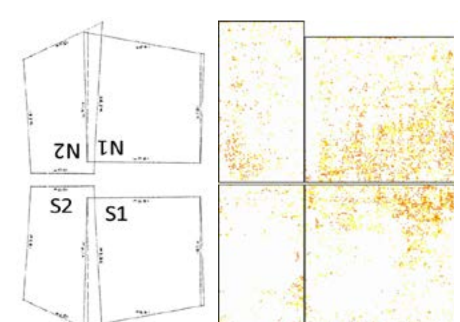


2.35 Damage atlas of the tile erosion, exfoliation and pitted tesserae


2.36 Tile color alteration and contamination


2.37 Tile color alteration and contamination


2.38 Tile color alteration and contamination



2.39 Damage atlas of tile color alteration and contamination

Tile deterioration conditions and classification of defects

The roof tile deterioration condition of the chapel can be roughly categorized in the following classification:

1. Erosion, exfoliation and pitted tesserae (degree: acute+, slight-)
2. Color alteration and contamination (degree: acute+, slight-)
3. Cracks and fractures (of individual tiles or adjoining tiles)
4. Efflorescence
5. Perforation

I. Erosion, exfoliation and pitted tesserae (Fig. 2. 31~2.35)

These are the tiles under erosion and attrition. White adobe would also exfoliate under these conditions (Fig.2.34). The deteriorations were classified as acute or slight according to the scale of deterioration (Fig.2.35). The coordinates of these fractures are as recorded on the graphic (Fig. 2.35).

The tile eroded, exfoliated and pitted tesserae occur mostly on roof-S2, roof-N1, and roof-N2. The main cause of erosion on roof-N1 and roof-N2 are most likely the nature of gradient and flow rate of the roofs (Fig. 1.34). Serious deteriorations at the bottom of roof-S1 are probably artificial damages.

II. Tile color alteration and contamination (Fig. 2.36~2.39)

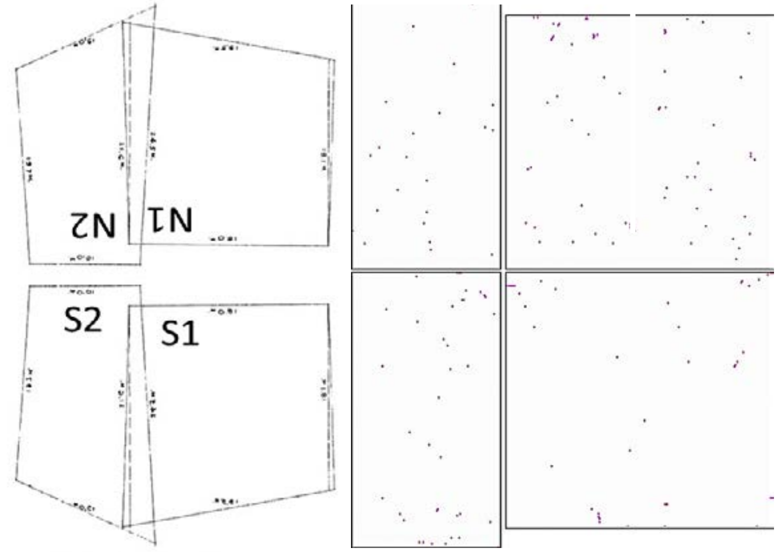
The tile color alteration and contamination distribution (Fig. 2.39) closely relate to the distribution of tile erosion, exfoliation and pitted tesserae (Fig. 2.35). The contamination on top of N1, N2 and the side frames are the most severe (Fig. 2.36). Areas close to the ground also suffer serious contamination (Fig. 2.38). The contamination on N1 and N2 was most likely caused by the gradient of the roof and the insufficient drainage of the roof gutter.

2. 40 Tile cracks and fractures

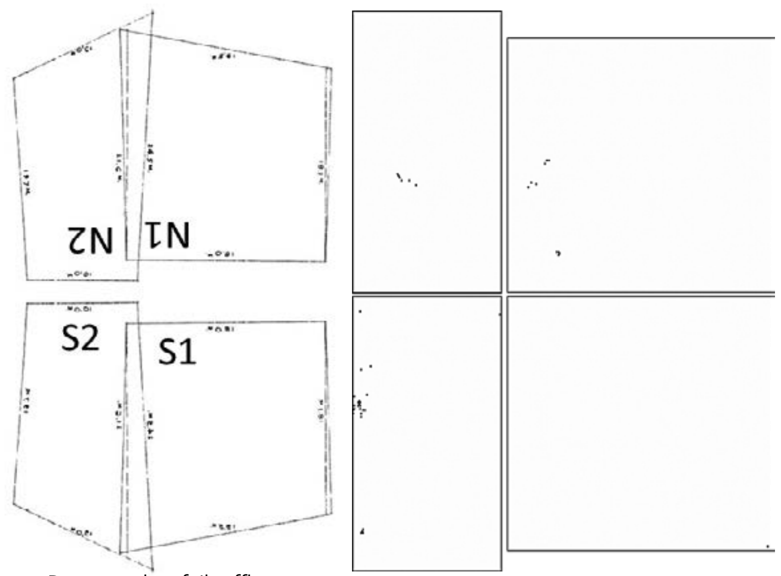
2. 41 Tile cracks and fractures

2. 43 Tile efflorescence

2. 45 Tile perforation

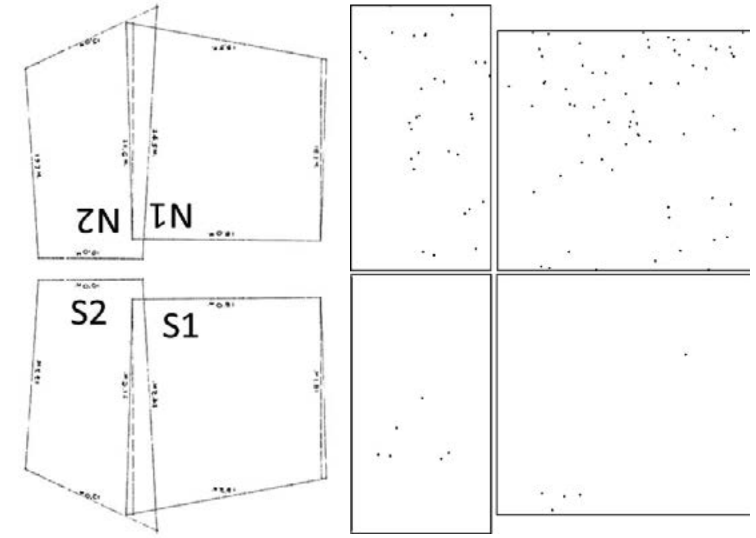


2.42 Damage atlas of tile cracks and fractures

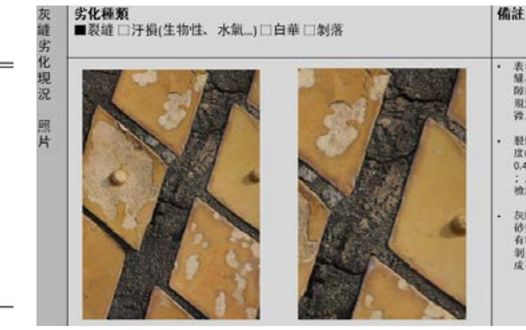


2.44 Damage atlas of tile efflorescence

2.46 Tile perforation

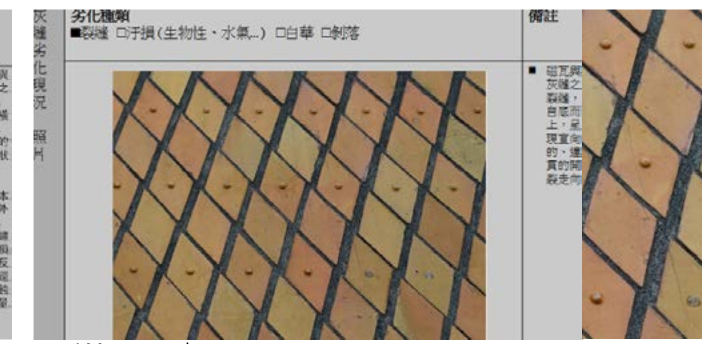


2.47 Damage atlas of tile perforation



2.48 Mortar crack

2.49 Mortar crack

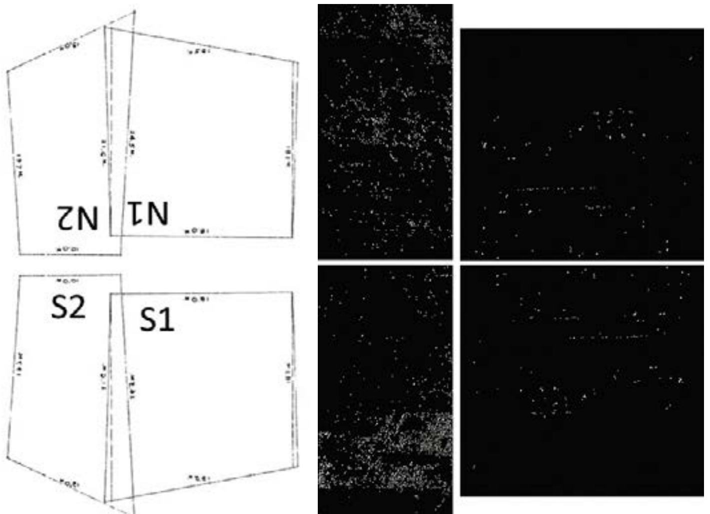


2.50 I.Mortar crack

III. Tile cracks and fractures (Fig. 2.40~2.42)
According to our primary and comprehensive investigation record (Fig. 2.42), individual and slight tile cracks and fractures are the major issues (Fig. 2.41). The cracks of adjoining cracks can form a long continuous fracture. However there are only two continuous fractures, one perpendicular and one horizontal (Fig. 2.40). Both of the fractures are only on the surface of the tiles, thus do not jeopardize the chapel structure.

IV. Tile efflorescence (Fig. 2. 43~2.44)
The efflorescent condition clearly scatters in several areas (Fig. 2.44). These are also the areas where apparent and acute deteriorations locate (Fig. 2.43).

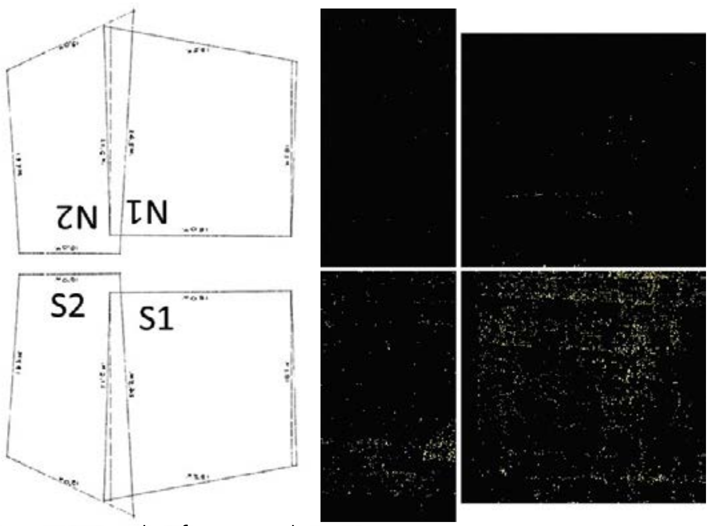
V. Tile perforation (Fig. 2. 45~2.42)
Tile perforation happens on the surface of the tile or on mastoids. Once a hole penetrates a tile, water or dust may easily permeate through the cement and erode the building structure.



2.51 I.Damage atlas of mortar crack


2.52 Mortar cavity and lacuna


2.53 Mortar cavity and lacuna



1.54 Damage atlas of mortar cracks


2.55 Mortar efflorescence


2.56 Mortar efflorescence

The condition and classification of mortar deterioration

Mortar deteriorations are classified into the following five categories:

1. Cracks
2. Mortar cavity and lacuna
3. Mortar efflorescence

I. Mortar crack (Fig. 2. 48~2.51)
II. Mortar cavity and lacuna (Fig. 2. 52~2.54)
III. Mortar efflorescence (Fig. 2. 55~2.58)

Treatment suggestions on the restoration of tiles and mortar deterioration

In conclusion, the heritage value and characteristic of the roof tiles are more decorative and aesthetic instead of waterproof function. However, so far the deterioration of the glazed tiles hasn't caused any leakage. Therefore, we strongly recommend "cleaning" as the first and primary treatmen. Moreover, the conservation requires the maintenance of an appropriate visual setting, e.g. the color, texture and materials of the tiles[4]. In other words, in order to maintain the authenticity of the original tiles, designed by Mr. C.K. Chen, the second step should be replacing tiles in critical deterioration condition, such as efflorescence, with the same batch of tiles stored in the school's warehouse.

4. According to "The Australia ICOMOS Charter (the Burra Charter)" article 8.

I. Tile Treatment1: Cleaning the glazed surfaces

i. Causes and factors assessment;
ii. Avoid damaging the structure;
iii. Mockup is necessary (use low hydraulic pressure on general contamination; neutral detergent on biologically deterioration)

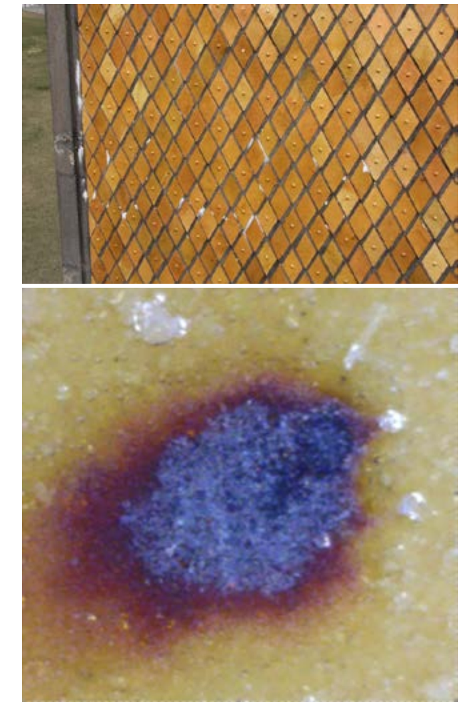
II. Tile Treatment 2: Replacement and safe removal of the damaged tiles

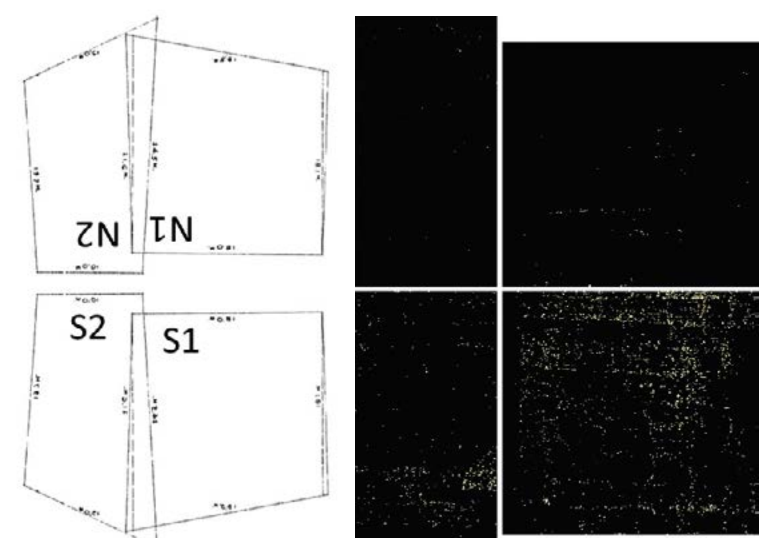
i. Replace with the same batch of tiles stored in the school's warehouse;
ii. The value of the original material is irreplaceable (compatibility and simultaneity)
iii. With the amount of tiles in store, ordering replication for replacement is not the priority of the current conservation.

III. Mortar Treatment 1: Repair of the surface and (re)fill mortars

i. Cement and Concretal-Lasur (SiO_2);
ii. The compatibility principal: introduced treatment materials without negative consequences
iii. The Reprocessable process: the current conservation treatment shouldn't hinder any future treatment.
iv. With the amount of tiles in store, replication is not a priority.

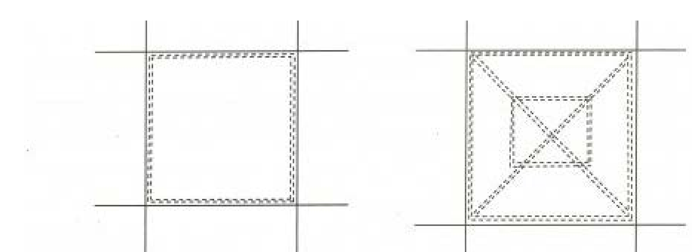
IV. Mortar Treatment 2: Regular maintenance


2.57 Mortar efflorescence



2.58 Damage atlas of mortar efflorescence


2.59 Inappropriate treatment


2.60 Replacement and safe removal of a damaged tile

Framework Proposal for Foundation Waterproofing

Structurally, Henry Luce Memorial Chapel is composed of four conoid (saddle-shaped) shell walls with one floor, together creating a contour consists of two linear and two curve lines. This gives the chapel a unique upward pitch. The five plates stand individually, disconnecting from one another. The floor caves in at the edges where the groundwork lays contiguous to the four walls, resulting an illusion of discontinuity between the floor and walls. Occasionally, water leaks into the groundwork and eventually hardens into efflorescence, a white powdery residue (Fig. 2. 61~2. 62).

2.61 Leakage and efflorescence condition at the caved in groundwork of Henry Luce Memorial Chapel, Taiwan.

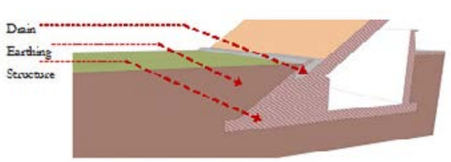
1. Issues and causes of exterior foundation waterproofing

Due to the immense campus lawn and the sprinkling irrigation system situating outside the chapel, both the site itself and the soil surrounding of Henry Luce Memorial Chapel are under high humidity. Water leakage at the caved in groundwork results from cracks and other structural discontinuities. Moreover, the wicking in tiny cracks and pores absorbs water from all directions- even upward porous building materials, such as masonry blocks and concrete also cause efflorescence and water leakage (Fig. 2.63).

2.62 Leakage and efflorescence condition at the caved in groundwork of Henry Luce Memorial Chapel, Taiwan.

2. Waterproofing suggestions

When water vaporizes and penetrates into the construction, the inner steel will corrode easily. Water penetration causes the concrete reinforcement to rust and expand, which in turn creates stress on the surrounding concrete. This can lead to spalling. During the corrosion process, the iron metal converts to iron ions at the anode, releasing electrons. The iron ions then react with oxygen, forming rust or iron oxides. As the iron oxides occupy more space than iron, the pressure on the concrete increases and cracking, spalling and delamination may occur. To prevent further corrosion mentioned above, the clefts and cracks must be filled. Since the surface fractures are slight, epoxy infused with pressure is the recommended solution. This will solve the corrosion issue effectively and create an alternation invisible on the surface of the structure. Moreover, as time marches on, in order to prevent further water vapor permeation, which will eventually cause more extensive cracking on the concrete, this program also suggest external waterproofing and permeable drain pipe, which will form an external isolating system (Fig. 2.64).



2.63 Diagram of the foundation section of Henry Luce Memorial Chapel, Taiwan.

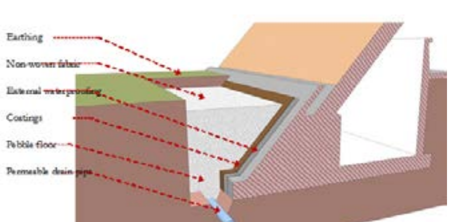
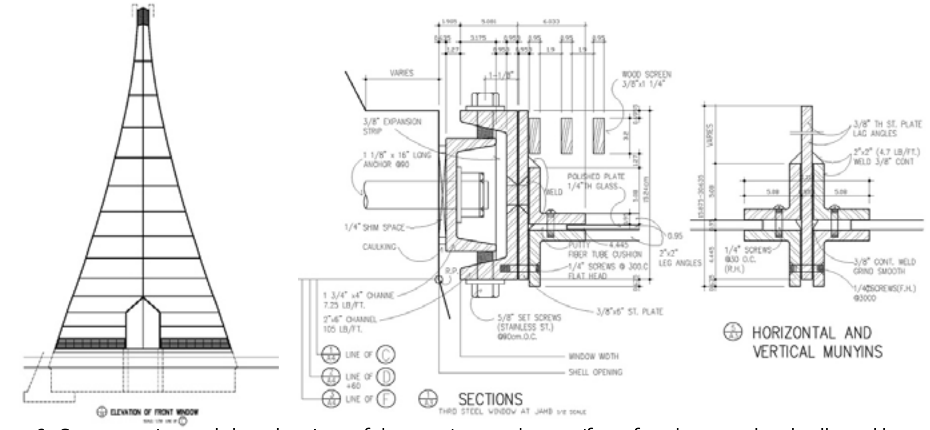
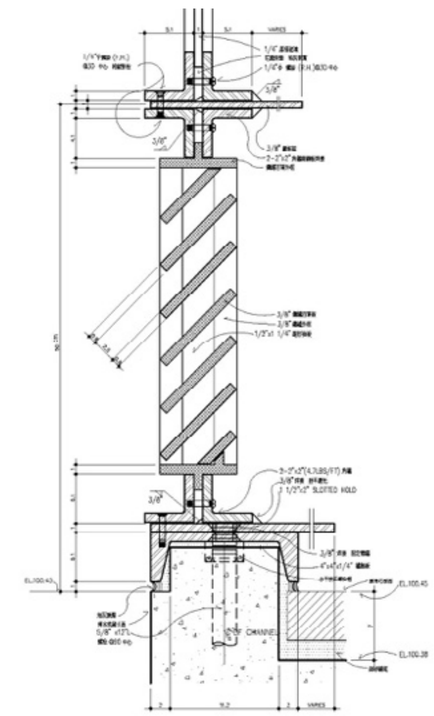


Fig. 2. 64 Diagram of renovation program for outside foundation waterproofing

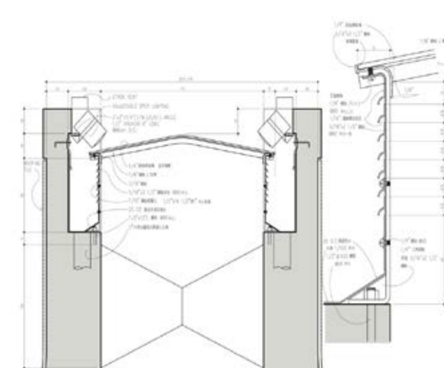


2.65 Segmentation and shop drawings of the openings at the east/front façade, owned and collected by Tunghai University

2.66 Detail of ventilation louvers.



2.67 Shop drawings of the ventilation louvers, owned and collected by Tunghai University.



2.68 Shop drawings of the ventilation louvers, owned and collected by Tunghai University.

Framework Proposal for the Openings

1. Analysis of the door and window construction with evaluation on its value as a cultural heritage

According to the original shop drawings owned and collected by Tunghai University, the openings of Henry Luce Memorial Chapel are composed of industrialized channel steel, angel iron, and steel plates. The combination rule of the openings is to fix a minor channel steel on the concrete structure in advance, then to compose a major one in a way contrary to the former by fastening bolts. Steel plates make up both the construction and segmentation of chapel's openings. Two sets of the angel steel fix the glass and were welded to the steel plates. The angel iron and steel plates are not aligned with each other. Instead, a 6mm interval is retreated, forming a clear constructional detail. In the same way, the larger channel steel does not connect directly to the structure. This reflects the above-mentioned constructional detail, rendering a unanimous detail design (Fig. 2.65).

In addition to the function of being interfaces of the four conoid (saddle-shaped) shell walls, the openings also play the significant role of buoyancy driven ventilations. Hot air with its lower density rises above the cold air, creating an upward air stream flowing out of the chapel from both sides of the skylight window and the upper ventilation louvers on top of the windows at the front and back of the chapel. The fresh air then flows into the chapel form the bottom ventilation louvers (Fig. 2.66~2.68). This design satisfies the interior thermal comfort in an economical and valid fashion.


2.69 The corroded frame of the east opening and silicone filled in the recessed structure.


2.70 Corroded upper rims of the frame in the façade of the chapel.

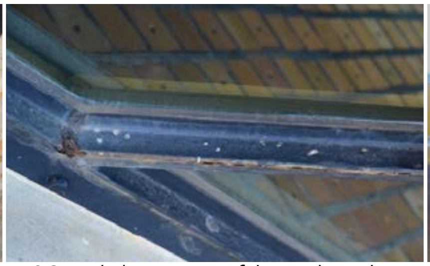

2.71 The chemicals added in the cooling towers aside the west windows caused critical corrosion on the bottom frames of the west openings.


2.72 The west windows and the cooling tower.


2.73 The distorted frame and broken glass at the west openings.


2.74 The frame of the south openings was corroded and the tiny gap between the frame itself and the structure was refilled with cement.


2.75 Corroded upper rims of the south window frame.


2.76 Corroded upper rims of the north window frame.


2.77 The welding points on the internal north openings were corroded and the interface between the steel plates and the steel channel was separate.


2.78 The internal louver boards of the west façade were corroded.


2.79 A close observation on the gaps between the frame and structure at the south openings.

2. Investigation on the deteriorations of the openings

The construction of Henry Luce Memorial Chapel began at the end of 1962 and was finished in 1963. It has served more than five decades. After a series of investigations and evaluations during 2014 and 2015, a preservation and conservation proposal with maintenance suggestions have been put forth as the following.

Investigation methods and the deterioration condition

This research goes through the deterioration items by visual examination, especially on the construction of glass, steel, and the manners they combine. Layers of paint coating were added throughout out years of maintenance. Through paint remover, this research was able to trace the painting history. Disassembling parts of the window construction reveal the structure and deteriorating condition of window frames.

I. Visual observation method

Aerial work platform and indoor workbench were set up to observe abnormities, which were photographed and documented accordingly (Fig. 2.69~2.82).


2.80 The splits between the north window frame, walls and interfaces are filled with cement to solve the leaking problem.


2.81 Water leaking through the interspace of a slight widow due to insufficient drainage function of the gutter.

II. Coating removal project and paint stripping system

In order to understand the paint coatings of Henry Luce Memorial Chapel, we discreetly chose Asur-#1180 as the paint-peeling agent to penetrate, dissolve and stripped layers of original paints through intumescence. We recognized different periods of coating through successive chemical reactions during the removal. Most of the steel coating color of Henry Luce Memorial Chapel is black. However, the interior steel coating color on the north and south sides are yellow. Therefore, we chose the west and the south sides as the sampling sources to carry out the coating removal project. On the west side coating removal test, a layer of orange paint is coated on the antirust priming paint with three layers of black paint on top; on the south side, a chrome yellow paint is painted over a layer of light yellow coating (Fig. 2.83~2.86). The frame colors of the openings coincide with the original paints used in the construction of the chapel.

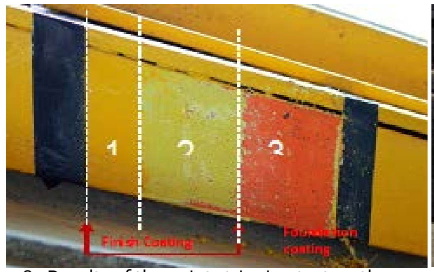
III. Deconstructing segments of the openings

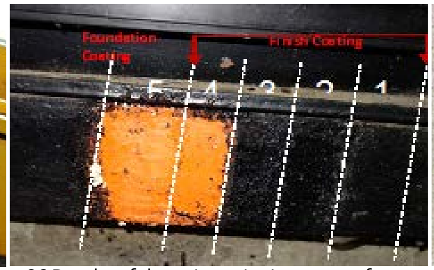
For the splits between the frame of the openings and the structure, we dismantled the inner side of the frames on the west façade. By doing the requisite inspection, we could go a step further to confirm the actual combination method and the deteriorating condition. After chiseling the concrete, we found out that the inner steel channels had already corroded. The adding of the screws was to fix the loose channels (Fig. 2.87~2.90).


2.82 Rainwater leaking into the chapel from the skylight window.


2.83 Coating removal project and paint stripping test on the frame of south openings. After cleaning, the test zone was defined by tapes and peeling paint agent Asur-#1180 was applied.


2.84 Scratching off the paints after the chemical reaction of expansion and foaming caused by the peeling paint agent.


2.85 Results of the paint stripping test on the frame of the south façade.


2.86 Results of the paint stripping test on frame of the west façade.


2.87 The inner side of the frames on the west façade was partially dismantled.


2.88 The screws were applied to fix the loose channels.


2.89 The inner side of the frames on the west façade was partially dismantled.


2.90 The inner steel channels were corroded.

Causes and Types of Deterioration at the Openings

I. Steel Corrosion

Steel corrosion caused by water vapor is the main deterioration at the openings. Places such as the external horizontal frames and the inner louver boards accumulate water easily. Capillary action, the ability of liquid to flow in narrow spaces without the assistance of, and in opposition to, external forces like gravity is another cause of steel corrosion. The welding points suffer serious corrosion from extreme heat. In addition, chemicals added in the cooling towers next to the west windows vaporized in the air and caused critical corrosion at the bottom frames of the west openings.

II. Loose Screws

The condition of some screws fixed on the steel channels of the opening frames is loose.

III. Splits between the Window Frames and the Walls

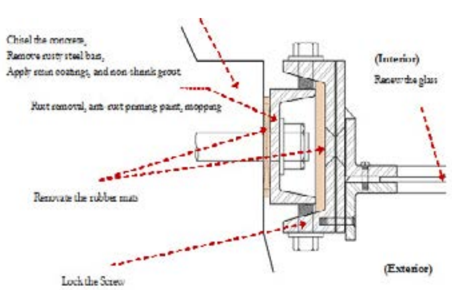
The splits between the window frames, walls and the interface were filled with cement to resolve leakage problem.

IV. Irrelevant waterproof and drainage system

Two iron drainage pipes with a diameter of 2" width were buried inside the structure during the chapel's construction period. However, only one is still in function at present time. Therefore the gutter is often full of water, and water eventually leaks into the chapel through crevices of the skylight window. Besides, waterproof function of the opening has degraded as the rubber mats inside the steel channels age or slacken.

V. Improper maintenance

Most of the gaps between the opening frames, the structure and other constructional details have been mended. Silicone and cement were probably added to amend the original water-repellent structure. The upper rims of the openings on the east and west façade were also sealed with steel plates. Moreover, the original design of the skylight window was altered. Its function as a buoyancy-driven ventilation medium no longer exists. The eastern ventilation is also blocked by the bookshelf placed in front of the shades. All these changes only solved partial problems; however, the original design concept and intention have been neglected, and the value of a cultural heritage have been reduced and compromised.



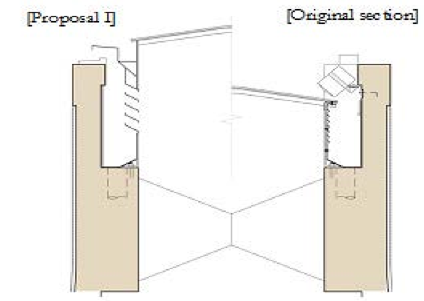
2.91 Proposal regarding anti-corrosion, rust prevention and waterproof solution of the openings

3. Repair and renovation proposal regarding the openings of the chapel

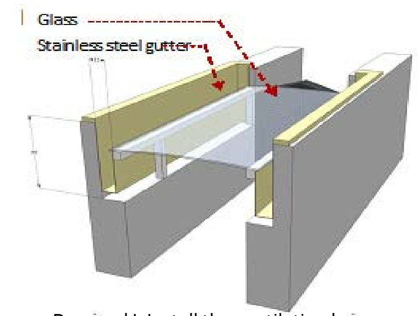
The restoration of the openings aims to conserve and maintain the original buoyancy ventilation concept designed by C.K. Chen. Other than buoyancy ventilation, anti-corrosion, rust prevention and waterproof are also the focus of this renovation.

An Anti-corrosion, rust prevention issue of steel and waterproof proposal on the openings

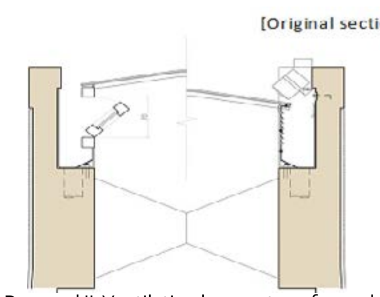
The interface of the window frames and structure is already showing rusts and cracks. In order to solve the steel corrosion problem, the waterproof issue on the openings, and restore the original structure details, the steel units must be dismantled from the openings and reapply antirust substances. As for the cracks of the reinforced concrete and rusts on the steel, the concrete must first be chiseled then follows the removal of rusty steel bars. After that resin coatings and non-shrink grout should be applied. The rubber mats, on which the waterproof function relies, should also be renovated this time (Fig. 2.91).



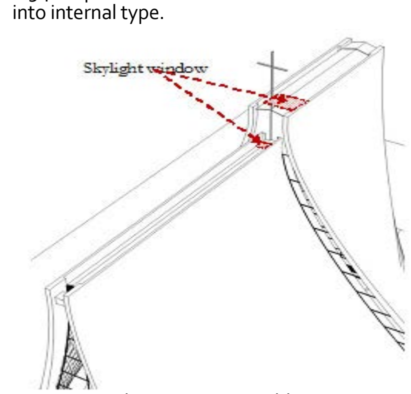
2.92 The current situation of skylight window.



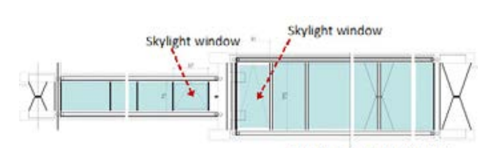
2.93 Proposal I: Install the ventilation louvers and gutter separately.



2.94 Proposal II: Ventilation louvers transformed into internal type.



2.95 Proposal III: Locate openable transparent panels near the middle of the original skylight window.



2.96 Proposal III: Locate openable transparent panels near the middle of the original skylight window.

Modification and improvement of the skylight window

The four conoid(saddle-shaped) shell walls that soar into the sky fulfill the aesthetic concept of "God is light. Panels of glass installed in between the walls created the interesting "thread of sky" lighting effects. The conservation of the skylight window must retain the original segmentation. Meanwhile, the ventilation function must be restored with a solution for the leakage issue. Three ventilation proposals are recommended as the following (Fig. 3.28~3.32)：

I. Proposal I: Install ventilation louvers and gutter separately.

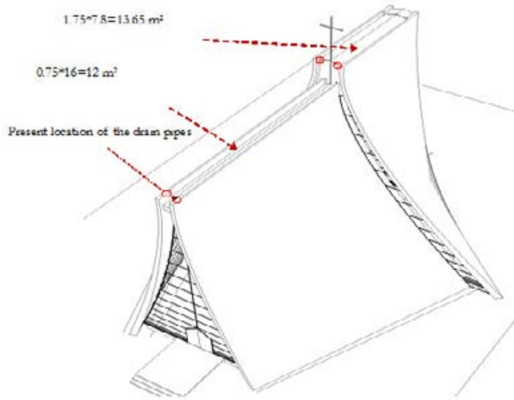
The louvers currently locate at the side-construction of the gutters. Therefore, the rain easily leaks into the chapel through the louvers during a heavy downpour or at times when there is a blockage at the gutters. Thus, for Proposal I, we suggest locating the ventilation louvers and gutter separately. The ventilation routes should be placed beneath the gutters. This way, if strong winds occur, the gutter will still maintain its drainage function. Although gutter section is limited, rainwater will still flow outward without gushing into the chapel. Even though the current suggested height for the skylight window is higher than the original height, the change should be undistinguishable at ground level.

II. Proposal II: Move the ventilation louvers into the chapel.

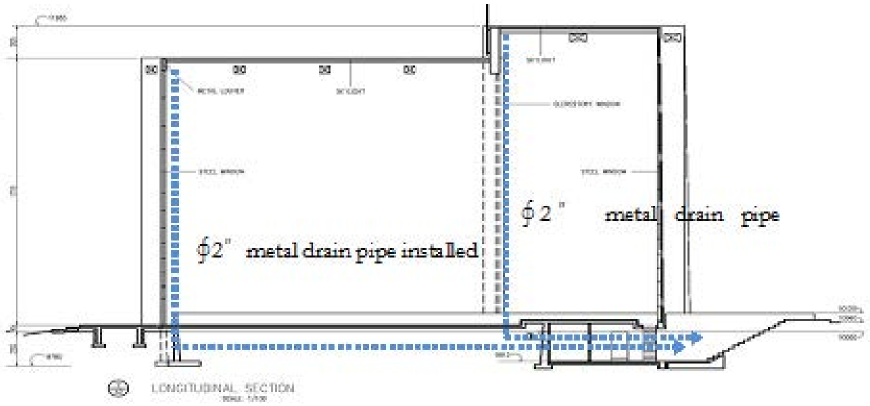
Not only does the louvers cause leakage problem during strong winds, they are also unable to be shut down like normal windows. In addition to the current leakage issue, the louvers also occupy parts of the ventilation space in the exterior construction. For this reason, we suggest moving the louvers into the chapel. This way, the depth of the original gutter may be deepened. Since the windows lie high above the ground, we suggest using electric switches to control the louvers in a way that the device remains invisible in the chapel . However, the repair and maintenance of the device will also be more difficult when situations such as malfunction or power outage occur.

III. Proposal III: Change the middle section of the skylight window into openable transparent panels.

Opening the skylight window directly increases the ventilation dimension to the fullest. The entrance and exist route of the air must flow through the ridge to balance the indoor airflow rate. Moreover, due to the height differences between the front and back skylight, installing openable panels at the center of the original skylight will also minimize the impact on visual appearance. However, maintenance may be difficult in practice in cases of equipment malfunction and power outage. The opening could be controlled by electric power. On non-rainy days, the panels can be opened as the chapel is in use. The indentations on the sides of the skylight should serve as gutters to improve and resolve the water drainage efficiency. According to the analysis of the investigation on thermal environment and simulation, the above three proposals shall enhance the environmental comfort level from its current enclosed skylight. In practice, Proposal II and III both have flaws during power outage. Therefore, we suggest Proposal I as the ultimate solution. However, the height of the skylight should be limited to prevent a nagetive impact on outward appearances.



2.97 projections measure of area and the present location of drain pipes



2.98 Modification and improvement of the gutters and skylights Proposal II: Hide the drainage pipes in the structure

Modification and improvement regarding the gutters and skylight

The skylight leakage is mainly caused by clogged pipes. This leads to poor drainage efficiency. Keeping the performance level of the pipes at a sustainable standard is the priority of the following conservation plan. Two iron pipes with 2" in diameter are buried inside the structure; however, only one is still in function. Therefore, the catchment is significantly insufficient (Fig. 3.33). As shown in table 3-1, placing a drainage pipe with a 50mm internal diameter in both of the gutters will be able to solve the problem. Two proposals are recommended as the following:

Table 2- 1
The relation between average rainfall and the internal diameter of drainage pipe

the internal diameter of the drainage pipes	average rainfall (unit: mm)					
	50	75	100	125	150	200
internal diameter ∮ (unit: mm)	Dimensions of rooftop reflection (m2)					
50	134	89	67	54	50	33
65	242	161	121	97	91	60
75	409	272	204	164	153	102
100	855	570	427	342	321	214
125			804	643	604	602
150						627

Resource: Development of Water-proof of Architecture，2000

I. Dredge the original drainage pipe and add lining pipes (Fig. 2.97). Change the pipes with smaller lining tubes, preventing water entering the structure through crevices of the pipes.

II. Hide the drainage pipes in the structure (Fig. 2.98). Put ∮ 2" metal drainage pipes along the sides of the internal wall and the sunken floor and guide the pipes to the exterior outfalls of the basement.

In order to keep the original appearance of the chapel, adding new facilities is always the last option. Therefore, the Proposal I should be considered as the prior solution after an evaluation on its feasibility. Proposal II should only be the alternative when Proposal I is found to be impractical.

Framework proposal for indoor floor

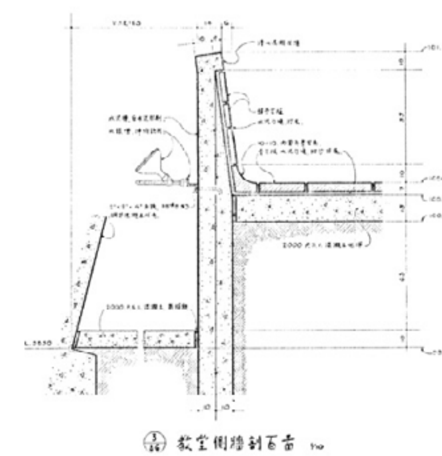
According to the original shop drawing data, limestone was the original flooring of Henry Luce Memorial Chapel (Fig. 2.99). Howevwer, during construction lauan was substituted for limestone. Insufficiency in acoustic absorbing materials might have been the cause of the modification. In 2011, the lauan floor was changed into wear-resistant wood floor, which lasts to this day (Fig. 2.100).

1. Investigation on the structure of the indoor floor

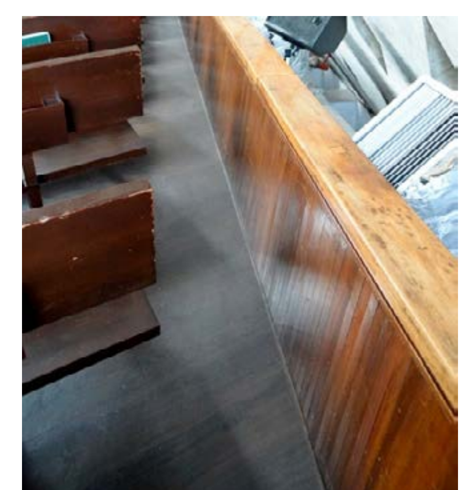
After partial dismantlement, we found the original Taiwan cypress angle section. Having been partially lodged into the RC floor, it remains as part of the structure during the replacement of the colored lauan floor. On above cypress angle section are new wood angle section, 15mm plywood, vibration isolation mat, as well as 9mm wear-resisting floor respectively (Fig. 2.101~2.102).

2. Evaluation on the value of indoor flooring as a cultural heritage, and an renovation proposal on the current floor deterioration

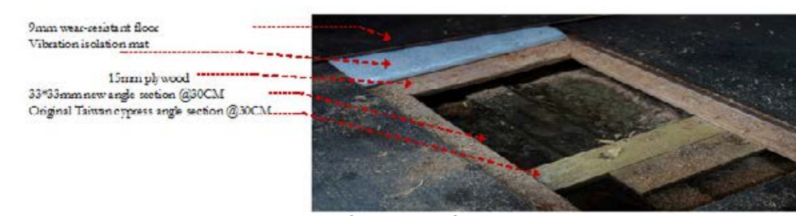
The replacement of the wear-resistant wood floor in 2011 has reduced and compromised the values of the interior floor as a cultural heritage. However, since at present it is still fit for use, immediate restoration of the original limestone design would be irrelevant. And yet, considering functionality, acoustics and embedded piping design, the floor should be replaced with solid wood in the future.



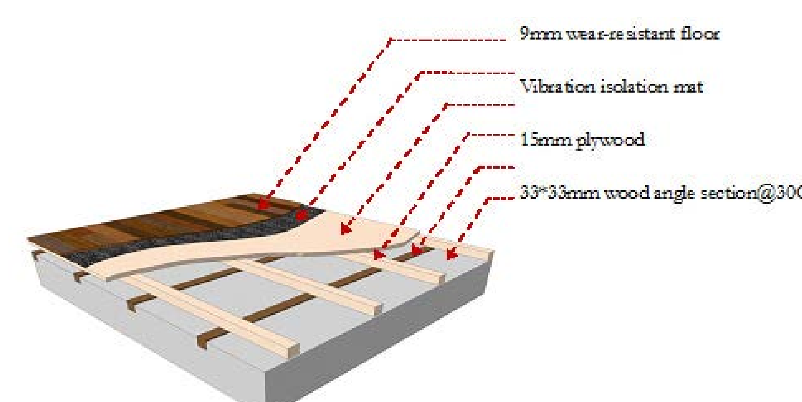
2.99 Limestone was the former floor consideration of Henry Luce Memorial Chapel.



2.100 The current floor is wear-resistant wood floor.



2.101 Investigation on the structure of the indoor floor



2.102 Illustration of the indoor flooring structure

3. Investigation and Discussion on the Conservation of Tiles of the Luce Chapel

General background of the research on the tiles of the Luce Chapel

Exposed to polluted and humid air, sunlight, and affected by aged mortar and cement, the tiles of the Luce Chapel have been subjected to different kinds of degradations such as crack, contamination, crumbling, efflorescence, perforation, biodeterioration, et cetera. The improper conservation and cleaning of the chapel in the past might also have caused various extents of damages to the tiles. As the deteriorated tiles disfigure the chapel and reduce its water resistant function, the conservation of the tiles became one of the core projects in the chapel conservation. In order to propose a suitable conservation program for the chapel, it is thus essential to first investigate the current state and the substance of the tiles.

Nowadays, a lot of countries pay high attention to the preservation of cultural heritage, which requires integration of technology and humanities. Regarding the conservation of monuments, historical buildings or relics, modern analytical techniques are increasingly employed for obtaining information on physical and chemical characteristics of the material components. This enables better understanding on the techniques of the buildings or relics and thus is helpful for the conservation.

The Complexity and variety of degradation on the tiles have made conservation and restoration a challenging task. In this work, optical microscopy, X-ray fluorescence and micro-Raman spectroscopy are complementarily used to analyze the tiles' microstructure, chemical composition, firing temperature, and current state of degradation of the glaze with the aim of providing the optimal method of conservation.

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Experimental and analytical techniques

Several reserved tiles in storage were selected and studied with different techniques. X-ray fluorescence and Raman spectroscopy are used for elemental analysis and structural study respectively.

1. X-ray fluorescence (XRF)

X-ray fluorescence (XRF) is a non-destructive elemental analysis tool widely utilized in the field of cultural heritage. When fitting X-rays impinge on the given materials, characteristic X-rays will be generated and emitted. As different elements have their proper characteristic X-rays of different energy, by detecting and analyzing these X-rays, chemical compositions in the materials can be identified. Depending on performance and sensibility of facility and experimental conditions, XRF can offer qualitative, semi-quantitative and quantitative analysis
In this work, the XRF equipment, M4 Tornado of Bruker, is a tool for sampling characterization using small-spot micro X-ray fluorescence (Micro-XRF) for information on composition and element distribution (2D mapping). The x-ray tube contains Rh as the target material and was used in an experimental condition of 45kV and 200μA with a 25μm beam spot. The chemical composition of body and glaze of the tiles and their white and black inclusions as well were all analyzed.

2. Micro-Raman Spectroscopy

Raman spectroscopy is a non-invasive optical technique permitting structural analysis of an object without sampling. Based on Raman effect or Raman scattering, it is employed to identify and characterize materials by deciphering their molecular structures. When light interacts with molecules, it can be scattered elastically if no energy exchange occurs before and after the interaction. This predominant mode of scattering is called Rayleigh scattering and is responsible for the blue color of the sky. On the other hand, if energy or wavelength of light changes after the interaction, the scattering will be inelastic. This is called Raman scattering or Raman effect. In a Raman scattering, the difference in energy between scattered and incident photons corresponds to the difference of molecular vibration energy levels, and is usually expressed in change of wavenumber (cm^{-1}) and called Raman shift. Since different materials have different molecular structures and possess varying Raman shift characters which can be reflected in Raman spectra as fingerprints, Raman spectroscopy is thus a powerful method for identifying materials. In recent years, it has been widely used for investigating artifacts or archeological materials including pigments, jades, gemstones and other art objects.
In this work, a Raman spectrometer equipped with 514nm and 633nm laser sources and with both 600 and 1800 lines/mm gratings is used to evaluate the firing temperatures of the glazed tiles. Glaze has non-crystal, amorphous glass structure in which the local structure and bond length of Si-O are associated with firing temperature. Therefore, firing temperature can be estimated by studying the molecular structure of Si-O in glaze through Raman spectra.
With complementary XRF technique for compositional analysis, Raman spectroscopy is also employed to identify black and white inclusions in tiles.


3.1a Tile THU-1, glaze


3.1b Tile THU-1, body


3.2a Tile THU-2, glaze


3.2b Tile THU-2, body

Results and Discussion

In order to gain information on ingredient and compositional homogeneity of the tiles, tiles of different areas were analyzed with XRF and Raman spectroscopy. As the tiles were glazed with iron-lead yellow according to XRF results, their manufacture technique could be mastered if content of iron and lead oxide, firing temperature and kiln atmosphere can be revealed. Besides, the black and white inclusions in the tiles have been identified as iron oxide and lead sulfate respectively. Both elements are associated with the cause of different kinds of degradation. The ensemble of data acquired provides crucial information for working out a practical plan for the conservation and restoration of the tiles.

1. Chemical composition

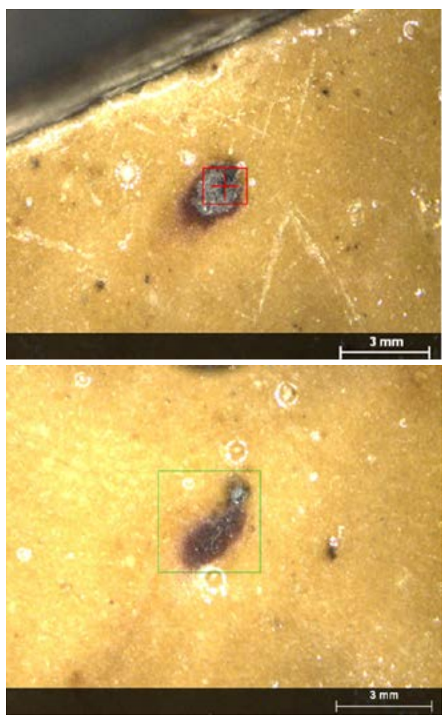
As the composition of the glaze and ceramic body of certain tiles shows similarity after analyzing several samples using XRF. Here lists only the result (Table3-1 and Table3-2) on two of the tiles (Fig.3.1 & Fig.3.2). In our study, due to the 25μm x-ray spot size, different small areas are analyzed for each tile to obtain information on homogeneity, i.e., the element distributions on the glaze. In the tables, glaze-n, body-n and ball-n represent the n th area investigated on glaze, body and papilla respectively. The chemical composition is described in oxide form with weight percentage (wt %) for major and minor elements and ppm for trace elements.
According to Table-1 and Table-2, the composition of the ceramic body is mainly silicon oxide (SiO_2 ,~72-73 wt %), alumina or aluminum oxide (Al_2O_3 , ~19-22 %), and other minor components, including iron oxide (Fe_2O_3 , ~1.5-1.8 wt %), potassium oxide (K_2O, 1.7-1.9 wt %), titanium dioxide, (TiO_2 , ~1wt %) et cetera. Regarding the composition in glaze, the content of SiO_2 is around 43-54 wt %, and 7-9 wt% for alumina. All glazes contain lead but a variety of concentration is observed in different tiles. The contents of PbO in the glaze of THU-1 and THU-2 are 34-47 wt % and 42-45 wt % respectively, indicating that the distribution of lead is less homogenous in THU-1. Moreover, minor iron oxide (Fe_2O_3, ~1.0-1.6 wt %) and other oxides were also detected.

Table 3-1 Chemical composition of tile THU-1 under XRF analysi

wt(%)	glaze-1	glaze-2	glaze-3	ball-1	ball-2	body-1	body-2	body-3
Na_2O	-	-	-	-	-	0.11	-	-
MgO	-	-	-	-	-	0.92	0.80	0.89
Al_2O_3	8.38	7.75	7.73	8.62	8.81	21.30	20.88	19.71
SiO_2	54.45	44.17	43.49	49.38	47.18	72.80	73.06	72.04
K_2O	0.91	0.48	0.43	0.77	0.77	1.96	1.94	2.06
CaO	0.15	0.18	0.19	0.18	0.23	0.26	0.29	0.30
TiO_2	0.52	0.52	0.56	0.72	0.53	0.94	1.02	1.10
Fe_2O_3	1.01	1.21	1.10	1.19	1.40	1.50	1.74	1.63
PbO	34.49	45.58	46.38	39.03	40.96	0.10	0.15	2.19
MnO(ppm)	58	113	125	71	62	144	204	158
CuO(ppm)	201	345	434	323	404	5	-	-
ZnO(ppm)	732	642	691	706	785	130	163	127
ZrO_2 (ppm)	-	-	-	-	-	856	795	670

3.3 Tile THU-5, glaze

3.4 Tile THU-6, glaze



3.5 Black inclusions of tile THU-5

Table 3-2 Chemical composition of tile THU-2 with XRF analysis

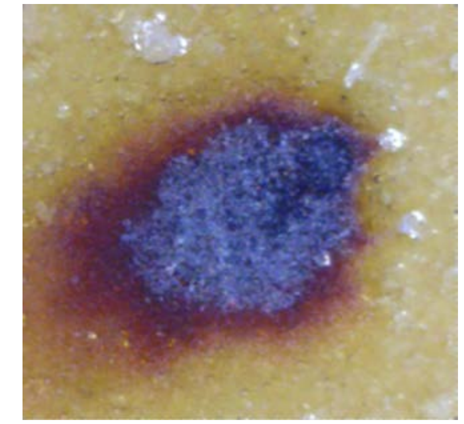
wt(%)	glaze-1	glaze-2	glaze-3	body-1	body-2	body-3
Na_2O	-	-	-	-	-	-
MgO	-	-	-	0.78	0.85	-
Al_2O_3	7.91	8.10	7.86	19.91	19.74	13.17
SiO_2	45.80	45.81	42.75	72.56	72.84	71.06
K_2O	0.60	0.66	0.53	1.83	1.74	1.23
CaO	0.50	0.47	0.50	0.41	0.27	0.29
TiO_2	0.47	0.49	0.48	1.09	1.00	0.72
Fe_2O_3	1.31	1.34	1.56	1.74	1.80	1.66
PbO	42.15	41.97	45.47	1.58	1.59	11.55
MnO(ppm)	107	99	121	146	233	183
CuO(ppm)	413	488	575	-	-	-
ZnO(ppm)	7498	10871	7741	321	332	1003
ZrO_2 (ppm)	4507	-	-	765	1138	1988

2. Black inclusions

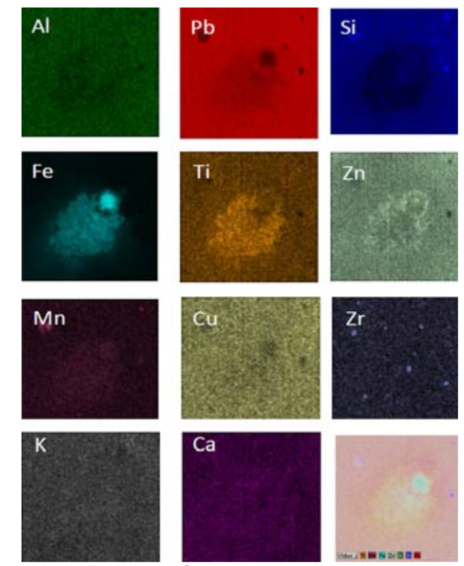
Some tiles contain black inclusions (THU-5, Fig.3.3) or have blackish-brown glazes (THU-6, Fig.3.4). They were elementally analyzed using XRF and the data acquired are as listed in Table-3 and Table-4. The results show that the content of Fe_2O_3 in the black inclusion of tile THU-5 is between 10-23 %, while that of the blackish-brown glaze on tile THU-6 varied due to inhomogeneous concentration of Fe_2O_3 (2-7%). Combined with the results of Raman spectroscopy (Fig. 3.10), the black inclusions were identified as iron oxides including both ferric oxide (Fe_2O_3) and magnetite (Fe_3O_4). The inclusion in THU-5 is mainly Fe_3O_4, while the blackish-brown glazes of THU-6 and THU-9 contain both Fe_2O_3 and Fe_3O_4. The color of magnetite is normally black, and ferric oxide is brown or dark red.

Table 3-3 Chemical composition of tile THU-5 under XRF analysis

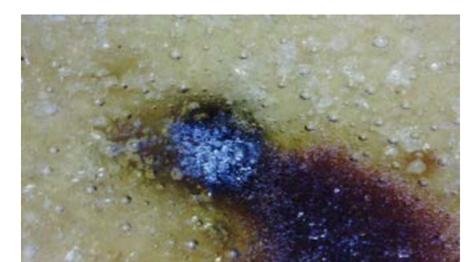
wt(%)	black-1	black-2	black-3	black-4	glaze-5
Na_2O	-	-	-	-	-
MgO	0.01	-	0.24	0.16	0.25
Al_2O_3	8.21	7.76	8.90	9.48	9.38
SiO_2	42.31	38.75	45.51	56.12	57.83
K_2O	1.02	1.04	0.96	1.19	1.19
CaO	0.45	0.43	0.24	0.34	0.35
TiO_2	1.05	1.09	0.50	0.54	0.52
Fe_2O_3	9.99	16.02	22.59	1.37	1.22
PbO	34.78	34.00	20.20	30.07	28.60
MnO(ppm)	449	739	722	108	119
CuO(ppm)	410	568	328	309	492
ZnO(ppm)	8950	6369	6888	5845	4884
ZrO_2 (ppm)	11882	1269	642	1027	944



3.6 Black inclusion in tile THU-5a



3.7 XRF mapping of THU-5 inclusions

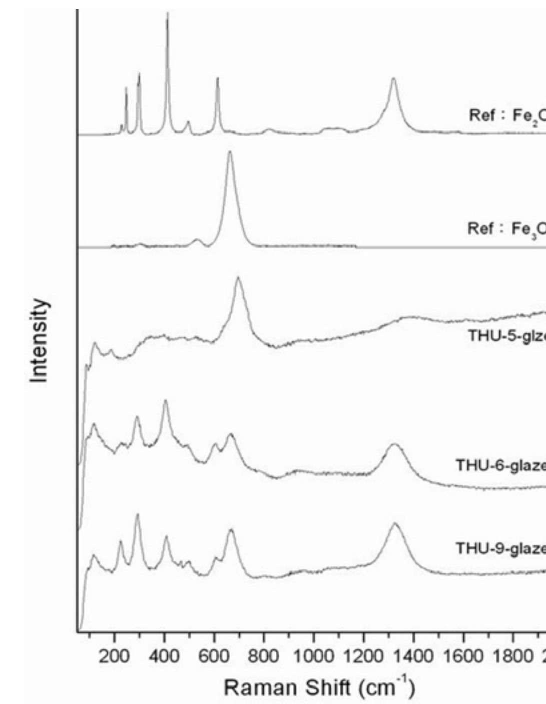


3.8 Black inclusion on tile THU-5b

3.9 Dark glaze on tile THU-6

Table 3-4 Chemical composition of tile THU-6 under XRF analysis

wt(%)	black-1	black-2	black-3	black-4	black-5	black-6	glaze-7	glaze-8	glaze-9
Na_2O	0.10	-	-	-	-	-	-	-	-
MgO	0.56	0.73	0.49	0.05	0.52	0.11	-	-	-
Al_2O_3	15.86	13.00	15.99	7.06	14.24	9.76	8.91	8.48	9.20
SiO_2	58.61	57.63	61.50	66.69	63.54	57.14	64.87	63.43	66.36
K_2O	2.51	2.21	2.78	0.93	2.32	1.10	1.52	1.57	1.28
CaO	2.99	1.98	1.53	0.66	1.02	0.94	0.41	0.38	0.29
TiO_2	1.16	1.26	0.98	0.63	1.06	1.06	0.60	0.49	0.46
Fe_2O_3	4.71	7.12	5.64	2.32	5.00	4.76	1.02	0.77	0.91
PbO	13.10	15.34	10.52	21.15	11.83	24.50	22.37	24.58	21.17
MnO(ppm)	700	515	416	160	330	208	68	64	75
CuO(ppm)	197	217	170	248	185	357	216	204	196
ZnO(ppm)	2401	5410	4313	3963	3306	4597	1967	1935	2403
ZrO_2(ppm)	811	1017	801	789	809	1122	754	755	638



3.10 Raman results of black inclusions

3. White inclusions in the glaze

Certain tiles of the Luce Chapel contain white or yellow inclusions in the glaze. These are the cause of hazy appearance. As the origin and the nature of the inclusions need to be explored, one of the reserved tiles, THU-10 (Fig.3.11) was studied using XRF and Raman spectroscopy and found out to bear the same characteristics mentioned above,.

According to the XRF results, sulfur (S), which should not be a main element in the glaze, is detected in the crystalized white inclusion. In addition, the concentration of calcium is much higher in the white inclusions than in other parts of the glaze. Raman spectra show that the molecular structure of the white particle corresponds to lead sulfate ($PbSO_4$).

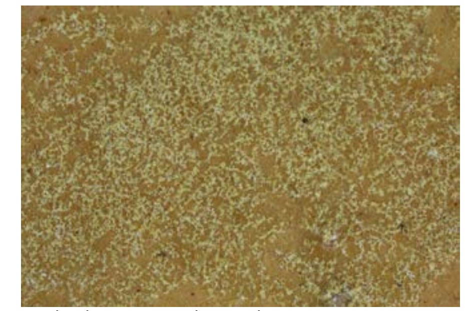
As it's abnormal that the tiles have been directly contaminated by $PbSO_4$. It's thus reasonable to conjecture that the white inclusions were formed from calcium sulfate (anhydrite, $CaSO_4$), gypsum (plaster, dehydrate, $CaSO_4 \cdot 2H_2O$), or plaster of Paris (hemihydrate, $CaSO_4 \cdot 1/2H_2O$). Both Gypsum and Plaster of Paris are architectural or building materials, which can be easily found in tile factories associated with architecure and construction. However the cause of the lead sulfate detection instead of calcium sulfate is still to be identified.

Gypsum transforms to plaster of Paris (hemihydrate) when heated at around 150 o C, and to calcium sulfate when heated above 250 o C. If gypsum or hemihydrate are mixed with lead glaze, $CaSO_4$ will first be formed during firing, then calcium sulfate, can react with lead in the glaze to form lead sulfate and release calcium when the heat raises to 500-800 o C:

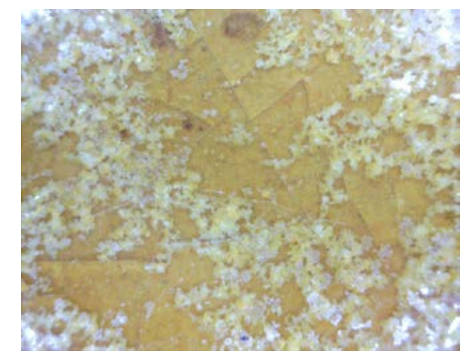
$$CaSO_4 + Pb^{2+} \rightarrow PbSO_4 + Ca^{2+}$$

Having a melting point of 1087 o C helps lead sulfate to withstand heat and maintain its crystal structure and distribution in the glaze without melting. At the same time, the released calcium becomes a part of glass phase of the glaze. This explains why a high concentration of calcium was detected in the white inclusion areas.

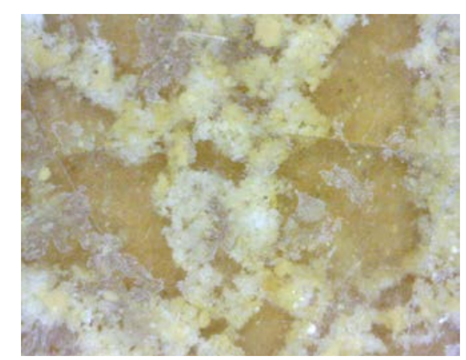
3.11a Tile THU-10, glaze



3.11b Tile THU-10, white inclusions



3.12a Tile THU-10, glaze (50X)



3.12b Tile THU-10, glaze (200X)

1. Colomban, P. et al. (2006). Raman identification of glassy silicates used in ceramics, glass and jewellery: a tentative differentiation guide, Journal of Raman Spectroscopy, 37, 841–852.

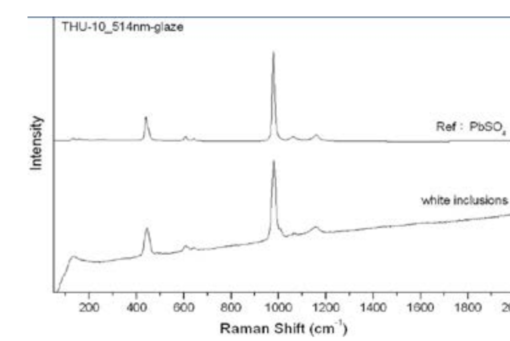
4. Firing temperatures

The firing temperature of the glaze can be estimated with the Raman spectra using the method set up by Colomban[1]. The Raman polymerization index Ip of the glaze in this study locates between 0.25 and 0.80, which indicates the firing temperatures to be between 600-800 o C.

The firing temperature of tile THU-10 is lower than 600 o C. This phenomenon is very likely to have been the result of gypsum or plaster of Paris contamination in the glaze, which eventually formed lead sulfate and released calcium into the glaze. The lead sulfate and calcium reacted as fluxes, which reduced the firing temperature. Due to the low firing temperature, the binding between the glaze and ceramic body is not as solid and is very likely to result in peelings or cracks.

Table 3-4 Chemical composition of tile THU-10 under XRF analysis

wt(%)	glaze-1	glaze-2	glaze-3	glaze-4 (white)	glaze-5 (white)	glaze-6 (white)	glaze-7 (white)
Na_2O	-	-	-	-	-	-	-
MgO	-	-	-	-	-	-	-
Al_2O_3	5.96	5.56	4.24	2.95	2.40	6.33	4.27
SiO_2	38.04	35.08	35.35	14.18	10.99	37.13	22.03
SO_3	-	-	-	26.09	35.56	28.41	15.47
K_2O	0.30	0.03	0.20	-	-	-	-
CaO	0.10	0.25	0.13	9.21	15.06	8.16	4.09
TiO_2	0.28	0.22	0.11	0.32	0.24	0.31	0.31
Fe_2O_3	1.02	1.03	1.16	0.64	0.46	0.72	0.77
PbO	53.32	57.01	57.90	45.93	34.90	18.58	52.36
CuO(ppm)	1346	1235	1673	460	284	333	418
ZnO(ppm)	8542	6851	7492	3837	3716	3242	6496



3-13
Raman spectra of white inclusions in tile THU-10

Table 3-6 Estimated temperature of the tiles on the Luce Chapel

Sample	Point measured	Ip	Firing T
THU-1	5	0.49-0.55	700
THU-2	5	0.54-0.76	700-800
THU-3	4	0.45-0.64	600-800
THU-4	3	0.40-0.42	600-700
THU-5	7	0.70-0.80	700-800
THU-6	7	0.48-0.60	600-800
THU-9	5	0.70-0.75	700-800
THU-10	10	0.23-0.30	< 600

3.14 The golden yellow tinge of Luce Chapel tiles

5. The color differences within the glaze

The external walls of the chapel are very rich in color. Although the main color pattern is golden yellow, the tiles are tinted with other colors such as light yellow, brownish yellow, olive green, et cetera. (Fig. 3.14). This color inconsistency can also appear on one sigular tile. According to Mr. C.K. Chen, this inconsistency isn't always the outcome of furnace transmutation:

On the day of glazed tile delivery, Mr. Gen Zong Wu ran to me and said, "I'm sorry! The color of the tiles is inconsistent. What should we do?" Due to the occurrence of furnace transmutation amidst firing, the color of each tile differed. Instead of golden yellow in the original design, the tiles were tinted with brown and green hue. I replied, "Wonderful! We were hoping for color inconsistency!" This would prevent dullness in color pattern; therefore, we asked the workmen to layout the colors in a staggered fashion..."22

Analytically speaking, the glaze used on these tiles was litharge glaze. Litharge, (lead oxide, PbO) usually appears as light yellow crystallizations. However, there are two types of crystallization for iron-lead. α-PbO is a tetragonal prism tinged with red, and β-PbO is the yellow crystallization under orthogonal crystal system. Usually, polishing β-PbO under room temperature releases α-PbO, and α-PbO would turn into β-PbO when it is been heated to 475~583 . After firing, lead melts within the glazed surface as PbO. When lead is solidified, the glaze color would correspond to the amount of PbO as the molecular structure spreads out in the lead. According to the above analysis, the amount of lead contained in each tile varies as its density varies. Having a firing temperature ranged of 600 to 800 ℃ caused the differences in partial molecular structure. The content of lead and subtle differences in firing temperature thus resulted the color variation of the tiles.

Moreover, the iron-lead glaze fired in oxidizing atmosphere could have also affected the glaze color. These glazed tiles contain 1-2 wt% of iron oxide, which also contribute significantly to the color of the glaze. Under normal oxidizing atmosphere, iron remains in ferric state(Fe^{3+}) within the glaze, and the color is usually yellow. In a reducing atmosphere, iron may reduce to ferrous state (Fe^{2+}) and the color would become greenish. This is also how the glaze color of celadon is formed. If firing was not well controlled in an oxidizing atmosphere, the tiles could show greenish yellow or olive tinge.

Traces of copper were also discovered in the study. Since copper is also a coloring element (it is green under ferrous state, and red under reduced state), even with an insignificant amount of copper, , the density and oxidizing atmosphere will also create subtle differences in the color of the glaze.

2. C.K. Chen, "The Wind of Tunghai," Taichung, Tunghai Univeristy

Tile degradation

These yellow diamond shaped tiles are the most essential decorations on the external walls of the Luce Chapel. After more than fifty years of exposure under the sun, rain, wind, and acid air, varying degrees of damages have occurred on multiple tiles. These damages include cracks, efflorescence, stains, perforations, molds, and glaze shivering.

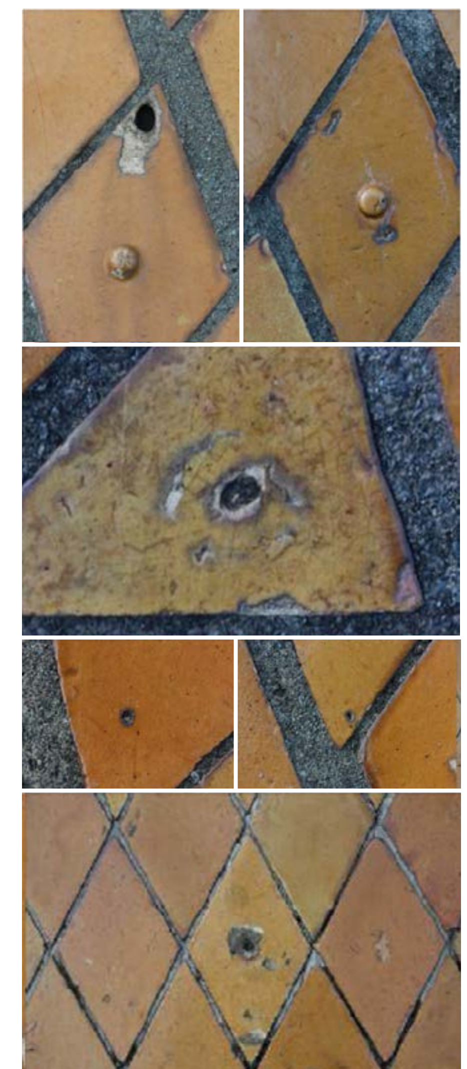
1. Fractures

Cracks, glaze shivering and fractures are all observed on the tiles of the chapel. The cause of these damages is associated with the firing technique, the nature of glaze, and the substance of material. The yellow iron- lead glazed tiles can produce sparkle and glorious appearance; therefore, it has been employed in Chinese buildings for a long time. The tiles of the Forbidden City are good examples. In the history of Chinese architecture, ingredients with high refractive index were usually applied for a radiant golden effect. With a high refractive index (approx. 2.5), lead oxide was more favorable than most other oxidative materials in ancient China. Besides bringing a glossy surface, lead oxide also decreases the firing temperature, thus reduces the cost of manufacture. The yellow glazed tiles of the Forbidden City contains a PbO concentration between 50-60wt%. According to the analysis of this research, the PbO concentration is between 34-50%.

As the body of the ceramic tiles is without lead oxide, its coefficient of thermal expansion is different from that of the glaze. Continuous exposure under the sun, rain, and thermal variation resulted damages. Thermal expansion and contraction are the factors that most likely have caused cracks on the glaze. Slowly, these cracks led to glaze shivering. Due to the low firing temperature, the binding between the glaze and ceramic body isn't very strong. The glaze would peel off more easily when the ingredients are mixed with contaminants (such as gypsum and plaster), which lower the firing temperature (sometimes down to 600°C or lower) and decreases viscosity. When lead oxide is not evenly spread, the above damage would accelerate. Once cracks or shivering occurs on the glaze, the tile would no longer be waterproofed. Eventually, this would lead to leakage and efflorescence in the building.

2. Black inclusions and perforations

Black inclusions, holes and perforations are observed on certain tiles (Fig.3.15). The black inclusions were composed of iron oxides including Fe_2O_3 and Fe_3O_4, which can result in corrosion and even perforation when exposed in the open air. Although the origin of these black contaminants is unknown, it could possibly have been the exposure under a working area with iron filings. Since these tiles were manufacture in mass production, a huge space must have been demanded for the storage of dried ceramic tiles before firing. Parts of the tiles could have been placed in a polluted environment where works such as iron cutting or welding took place. In these environments, iron filings would have filled the space and contaminated the tiles, leaving black and brown specks on the glaze after firing.



3.15 Black hole on the tiles of the Luce Chapel (southern wall)


3.16a Bell tower

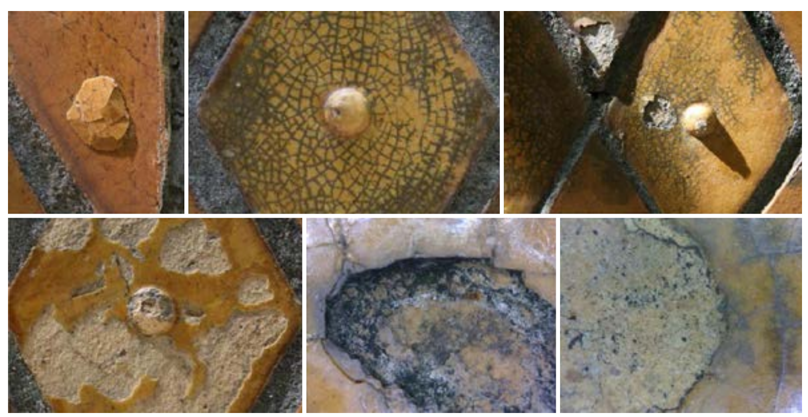

3.16b Bioteterioration of the bell tower

3. Biodeterioration

Being surrounded by trees, ventilation around the bell tower (Fig.3.16a) is not as ideal compared to the chapel. The moisture can thus cause biodeterioration and accelerate the forming of damages such as serious cracks of the tiles (Fig.3-16b,3-17). The same problem was also observed on the chapel walls around areas close to the lawn (Fig.3.18).

4. Efflorescence

The main component of efflorescence is generally calcium carbonate ($CaCO_3$). When concrete or mortars are subjected to moisture, water can react with CaO and form $Ca(OH)_2$, which later react with CO_2 in the air to form $CaCO_3$. Hence the key factors for the formation of efflorescence are water, calcium oxide within the building material, and CO_2. The tiles contain generally low calcium (< 1wt%). However, the glaze of some tiles consist of white and yellowish inclusions of $PbSO_4$ bears a higher calcium concentration and can easily lead to efflorescence. This is because lower firing temperature would ultimately result in cracks of glaze and introduce water/vapor, which would react with CaO to for $CaCO_3$.


3-17 Biodeteriorations, cracks and crumblings (bell tower)


3.18 Biodeteriorations, cracks and crumblings (on the Luce Chapel)

Discussion on conservation and restoration of the tiles of the Luce Chapel

above analyses and discussions have mapped out the overall characteristics and current state of the tiles. Although the aesthetic value of the tiles is not to be ignored, the function of waterproofing and heat insolation in the original design is equally important. Deteriorations such as cracks, peeling, perforation, efflorescence, mold, and moss not only influence the appearance of the chapel, but also affect the original function, creating the problem of seepage. Therefore, tile repair should be one of the core projects in the conservation of the Luce Chapel, and the restoration needs to take place as soon as possible. Among all the deteriorations, glaze shivering is one of the most serious of all, making the repair of glaze a very challenging task.

Although the Luce Chapel isn't a historical monument, it still holds high historic and aesthetical value in the perspective of modern architecture development. Its conservation should meet the principles of modern cultural asset conservation. Modern conservations put a lot of emphasis on restoration ethics regarding authenticity. Factors such as style and design, material and substance, utility and function, tradition and technicality, location and occasion, spirit and emotion, other internal and external factors33, et cetera, are all important discussions for the authenticity of modern conservation. In restoration practices, the following three principals must be kept: minimum interference, reversibility, and identifiability. For the conservation of the tiles of the Luce Chapel, these principals of authenticity and restoration ethics are also worth noting.

In Article 9 of the Venice Charter 1964, it is stated that the aim of restoration is "to preserve and reveal the aesthetic and historic value of the monument and is based on respect for original material and authentic documents. It must stop at the point where conjecture begins…" In the process of tile restoration, keeping the original aesthetic and historic value is indispensible, and surely the restoration must be preceded under the respect toward original material and authentic documents. However, defects of the original firing techniques and material substance have become problematic for long-term conservation of the tiles, and these were unaware issues at the time of construction.

Historically, the concept of modern cultural asset conservation does not exist, and many glazed tiles of ancient monuments were replaced with new ones or ones from the original stock in storage. The tiles replaced usually were not preserved. However, with the concepts of modern cultural asset conservation, much attention has been paid to the authenticity of original material. The traditional repair method has been challenged with the concept that if replacement kept been made, antique will become new, and eventually there will be no more historical monuments or relics. Nevertheless, the defects and life span of original building elements often conflict with the goal of "conservation." Luckily, Article 10 of the Venice Charter leaves flexibility by indicating "where traditional techniques prove inadequate, the consolidation of a monument can be achieved by the use of any modern technique for conservation and construction, the efficacy of which has been shown by scientific data and proved by experience." This is certainly worth taken into account for the conservation of the tiles on the Luce Chapel.

Tiles of the Luce Chapel clearly show flaws in water resistance, aesthetic value, and modern cultural asset conservation. Inevitable deteriorations such as glaze shivering has resulted the loss of original functions initially set for these tiles.

3. The Nara Documents on Authenticity, 1994

In other words, these are the flaws of traditional techniques. Through scientific analyses, this study has identified the inadequacy of these tiles. Experiences have proven the efficacy of certain modern technology to be sufficient in achieving the original functions and providing sustainability.
Beside relative professional techniques, cost, conservation schedule, and user demands should also be considered in the process of tile conservation. Different restoration method has its own objective value. This study will propose several feasible restoration suggestions based on the results of various tile analyses conducted in this research. These suggestions are made based on the above-mentioned principals. Technical issues pertaining to the conservation will require further investigation, analyses, research, and discussions. In order to choose the optimal solution, relative experiments and critical comparative studies must take place with considerations regarding execution and other possible difficulties.

1. Consolidation

With a high rate of adoption on buildings of various western historical eras, the conservation and restoration of tiles receives much attention. In the past decade, relative researches relating to scientific analyses have been flourishing. Although the adoption of ingredients and firing techniques varies in each western and eastern historical era, there are still similarities in deterioration such as stain, cracks, glaze crazing and shivering, biocontamination, perforation, diminished water resistance, et cetera. Cracks, glaze crazing and shivering are common problems observed on deteriorated tiles, making consolidation of degraded tiles a central task of conservation.

Adhesives

Adhesives are used to strengthen the bond between the glaze and ceramic body. By priming pores and fissures, adhesives also enhance the waterproof function of the tiles. There are different kinds of adhesives, and considerable scientific researches have taken place in order to identify the ideal solution for repairing ceramics. However, several principles need to be put into consideration as application of adhesives is implemented. First, it should be reversible so that it can be easily removed when needed. Second, the viscosity of the adhesive must be lower than that of the ceramic material to prevent fractures. It should also provide long-term stability and good resistance against environmental degradation factors. Lastly, the adhesive should be colorless to avert influences on the appearance and color of ceramics.
In ceramics conservation, Paraloid B72 has been proven and commonly believed as an excellent adhesive for consolidation. Paraloid B72 (PB72 or B72), a product of the US company Rohm & Hass, is a thermoplastic acrylic resin composed of ethyl methacrylate (70%) and methyl acrylate (30%) copolymer. It is stable, flexible, and fast drying, taking only 24 hours to harden and remains transparent over a long period of time. It gives a good bond when applied to both surfaces at the joint and can also easily be reversed (removed). Paraloid B72 can be dissolved in acetone, ethanol, toluene and xylenes. For the conservation of tiles, Paraloid B72 can be diluted in acetone. In addition, it can permeate into cracks and pores for consolidation through brushing or spraying. When required, it can be removed using acetone.
Though Paraloid B72 seems to be an ideal adhesive for ceramics consolidation, experiments in the study of tile conservation of the Forbidden City, Beijing show that the mixture of fluorine resin and Paraloid B72 at the ratio of 8:2 delivers a better performance than pure Paraloid B72 in hydrophobicity and freeze resistance.44 Regarding the tiles the Luce Chapel, it is certainly necessary to conduct some adhesive experiments regarding aging, consolidation, mechanical strength, water resistance, etc., and use different adhesives to find out the best consolidation solution.

Fillers

In case a tile can't be detached when parts of the glaze or the entire glaze on a tile is missing, it is suggested to repair and embellish the appearance of the tile with fillers under the principle of reversibility. According to the experiments performed by Durbin55, the mixture of 98% polyster resin and 2% peroxide hardener is the best formulation to fill and repair the missing glaze. It is softer than ceramic and thus easier to be cut and embellished to form the thickness required. Besides good consolidation and water resistant function, this type of filler is also stable and long-lasting. With a reversible nature, it can also be easily removed with dichloromethane. However, its color will turn light yellow under the exposure to UV radiation and humidity after several years; therefore, an additional layer of coating is suggested for protection. For the tiles of the Luce Chapel, environmental aging experiments are also required.

Nano-coating materials

Based on aging simulations, implementing adhesives and fillers to strengthen and patch deteriorated tiles can extend the sustainability to decades or even longer (depending on the environment of which the building is exposed to). However, all buildings are always exposed to air, UV radiation and other pollutants, and conservation materials will eventually age due to these deterioration factors in the environment. Once degradations appear, the repairing process will again be in demand. On the other hand, the tiles presently in a good condition will also be gradually affected by thermal variation, moisture, acid, and biological pollutants, and will result in deterioration due to the nature of the materials. One of the deteriorations caused by the nature of material and environment is that the high degree of lead contained in the glaze has a coefficient of thermal expansion very different from that of the ceramic body, and is due to crack after some time.
The key to prolong the life of these tiles is to adopt efficient preventive maintenance to reduce the impact of environment. For example, proper coating would be a good choice of prolongation.
There are pros and cons between the adoptions of traditional organic coating materials and polymer materials. Lately, with the advancement of nano-technology, certain nano-materials have been developed for the conservation of cultural heritage including paper, bronze, marble, architecture, and ceramics. Though there are different types of nano-materials, in the field of stone, ceramics and tiles conservation, nano-TiO_2 and nano-SiO_2 are most studied and tested in conservation practices. They have been proven to be effective in preventing UV radiation, biodeterioration, oxidation, acidification, and other environmental pollution. More importantly, these nano-coating materials do not alter the colors of the original art pieces.
Nano-TiO_2 is widely used as coating material in practice. It is effective in inhibiting biodeterioration, and insulating air pollution. It has self-cleaning function and brings no color alteration to the coated material. Besides, modified nano-TiO_2 could be added into adhesive Paraloid B72 and fillers to enhance the consolidation and prolong the life span of the tiles, adhesives, and fillers. Having an excellent surface- active nature and adsorption capacity, Nano-SiO_2 bonds strongly to a tile to form a thin protective layer. Its signature optical character works well in absorbing UV rays, reflecting infrared rays and moderating damages caused from

4. Zhao, Jin, Li, Wei-Dong, Lu, Xiao-Ke, Lo, Hong-Jie (2009). Conservation Study on the Glazed Tiles of National Palace and Academic Discussions Regarding the Scientific Technology of Antique Ceramics in 2009, pp. 125-134.

5. Durbin, L. (2014). Architectural Tiles: Conservation and Restoration, pp. 154-155.

sunlight. It also has a self-cleaning function. Like nano-TiO_2, it can also extend the life span of an artifact or building material when applied in adhesives and fillers.
With multiple environmental deterioration factors and defects in material composition and structure, proper adoption of nano-coating materials is suggested for the conservation of tiles of the Luce Chapel to prolong life span. However, necessary experiments should be conducted to optimize the coating materials and confirm the methodology before applying to the tiles of the chapel.
It is worth noting that, besides Nano-SiO_2 and nano-TiO_2, the team of Piero Baglioni, Professor of Department of Chemistry and CSGI, University of Florence, Italy, successfully used the mix of $Ca(OH)_2$ and $Mg(OH)_2$, and other alkoxides for the conservation of stones, ceramics and other materials66. Their experiences can also serve as references for the tiles conservation of the Luce Chapel.

2. Imitation

Certain deteriorated tiles can be repaired and consolidated with suitable adhesives, fillers, and even nanoparticle coatings to prolong their life. However, for some seriously damaged tiles and the ones with glaze totally peeled off the bodies, replacement with imitations should be considered.
If a component of a building is seriously damaged, it is generally substituted with a new replacement. Although reserved tiles in storage meet the authenticity principle, due to their limited number, insufficiency will occur in due course for long-term conservation. Imitation of the original tiles will be a low-cost replacement. Besides, the Luce Chapel is only 53 year-old and is categorized under modern architecture. Compare to other ancient architecture, its age value77 isn't the most significant issue at the present stage of preservation.
Technically, scientific analyses can offer information on the chemical composition of the glaze and ceramic body with a range of firing temperature. Besides, firing atmosphere could also be mastered through simulated experiments. However it is worth noting that due to the defects in composition and structure, the original tiles aren't perfectly competent in their waterproofing function and deliverance of glorious golden yellow image, which were the attribution originally intended to achieve in the original design. Under the principle of honoring the original aesthetic, improvements on ingredients and firing techniques should be made to fix the current defects of cracks and glaze shivering. Hence similar color and texture shall be secured and the waterproof function will be obtained.

3. Re-firing tiles

Imitations for replacing damaged tiles may be a good means of conservation. However, when there is a large-scale replacement, the questions about authenticity will be raised. If the old and deteriorated tiles are always and continuously replaced by new ones, no more original tiles will remain on the chapel. As authenticity of material is one of the most essential issues in conservation, it is proposed to retain the tiles and process re-firing with better mixture of ingredients and advanced techniques to surmount problems involving thermal expansion, water resistance, perforation, et cetera. One of the examples is the tile conservation of the Forbidden City in Beijing. In the conservation, certain glaze of the tiles was seriously damaged, and the tiles were falling. Their glazes were re-fired with ameliorative formula in the conversation project. However, the tiles in the Forbidden City are relatively easily to be removed from the roofs, while the tiles of the Luce Chapel are embed into mortars and cements, which are difficult to be separated from the wall. The detachment of tiles in the case of the Luce Chapel is thus a time and money

6. Baglioni, P. et al., Nanotechnologies in the Conservation of Cultural Heritage: A compendium of materials and techniques, Springer, 2015.

7. Alois Riegl (1858-1905) mentioned monuments have their age value in Der moderne Denkmalkultus: Sein Wesen und seine Entstehung (The Modern Cult of Monuments: Its Essence and Its Development), written in 1903.

consuming engineering. Therefore, comprehensive investigation and evaluation on methods of conservation are required.

4. Detachments of damaged tiles

Both imitations and re-firing tiles will encounter the challenge of detachment, which requires special repair methods and techniques. Traditionally, a hammer is used to knock off the tiles. It is a quick but destructive solution, which can destroy the tiles. Besides, pounding will also influence the structural stability of the wall. Thus, the ideal treatment is using a small hand-held angle grinder fitted with a diamond-edged cutting blade to carefully cut the tiles and remove them from the wall. The tiles removed should be well preserved for re-firing, exhibition or other purposes under the consideration of cultural heritage conservation.

5. Biodeterioration

With the surroundings of trees and lawns, the contamination sources of environmental microorganisms follow the chapel all year round. Mold, lichen and moss can easily attach on the tiles under the humid environment. If cracks, factures or pores exist, microorganisms can penetrate and grow in tiles and accelerate deteriorations.
Though water and certain solvents can be used to clean the attached microorganisms, they can also make the crack and crumbling states worse during the cleaning process. The better way of fixing seriously damaged tiles is to replace them with spare or re-firing tiles. For the tiles slightly polluted by microorganisms, cleaning and removal of the bio-contaminants is suggested. After cleaning, adhesives and/or fillers should be implemented.

6. Black holes and perforation

The black inclusions in the tiles of the chapel consist of Fe_2O_3 and Fe_3O_4, which are contaminants of iron filings during fabrication. However, these inclusions, being iron oxides, can corroded when exposed to humidity and harmful gases such as SO_2, CO_2, NO_3^-, Cl^- and H_2S, which will react with water and form acid solvent, rusting the iron. If the air contains salt, the Cl^- element can react with iron and break the structure of the tiles. The corrosion can result in black holes or perforation, which will eventually cause seepage.
In order to prevent iron corrosion, insolation is necessary. Paraloid B72 is often employed on coating iron objects for corrosion prevention. In this case, B72 seems ideal as the composite materials consisting ceramics and iron oxides. Besides, nano-TiO_2 or nano SiO_2 could be added into Paraloid B72 to enhance water resistance, UV protection and acid and alkali resistance. Moreover, after consolidation, fillers can be employed to create a glaze-like effect.

Conclusion

As one of the "Keep It Modern" architecture, the Luce Chapel is certainly one of the most representative modern architecture in the 20 th -century. Its preservation is thus internationally significant and can enhance the development of modern architecture conservation.

Besides its waterproof and heat insolation function, the golden yellow tiles are also highly decorative and aesthetically remarkable. Tiles are one of the most important elements that reflect the intangible spirits of the Chapel. Therefore, tiles subjected to varying extent of complicated deteriorations should be considered as one of the most essential restoration objects in the conservation of the Luce Chapel. In order to better understand the physical and chemical characteristics and current state of the tiles, different and complementary analytical techniques, including X-ray fluorescence, Raman spectroscopy and other optical tools, were employed to investigate the glaze, ceramic body, and inclusions of some tiles. The information obtained on chemical composition, firing temperature and inclusions nature is critical for exploring the possible means of conservation.

According to the analyses, the iron and lead in the glaze are responsible for the effect of golden yellowish tinge. This study also shows that the coefficient of thermal expansion of glaze is different from that of the ceramic body, resulting crack and glaze shivering when the tiles suffer thermal variation.

Moreover, this research also observed tile deteriorations accelerated by humidity and environmental microorganisms at the area around the bell tower and the lower parts of the chapel walls.

The black inclusions were identified as iron oxides, which can corrode when exposed to moist air containing harmful gases. The corrosion can then damage the tiles and form black holes or perforation and cause seepage. In addition, white and yellow inclusions in the glaze are composed of $PbSO_4$, with high content of calcium, which may cause efflorescence when reacting with CO_2 under moist condition.

Regarding different types of deterioration, possible conservation treatments are as suggested. Paraloid B72 is proposed to be an ideal adhesive for consolidation, while polyster can be used as the filler for tiles with missing glaze. Besides, nano-TiO_2 or nano-SiO_2 could be considered as coating materials to prevent UV radiation, biodeterioration, oxidation, acidification, and pollution. However, more related experiments need to be implemented to optimize the materials and treatments applied in future conservation.

This preliminary study offers essential information for the conservation of the Luce Chapel tiles. However, as conservation involves interdisciplinary knowledge, value judgment, budget, and final conservation practice, more comprehensive discussions are required to determine the optimal conservation projects.

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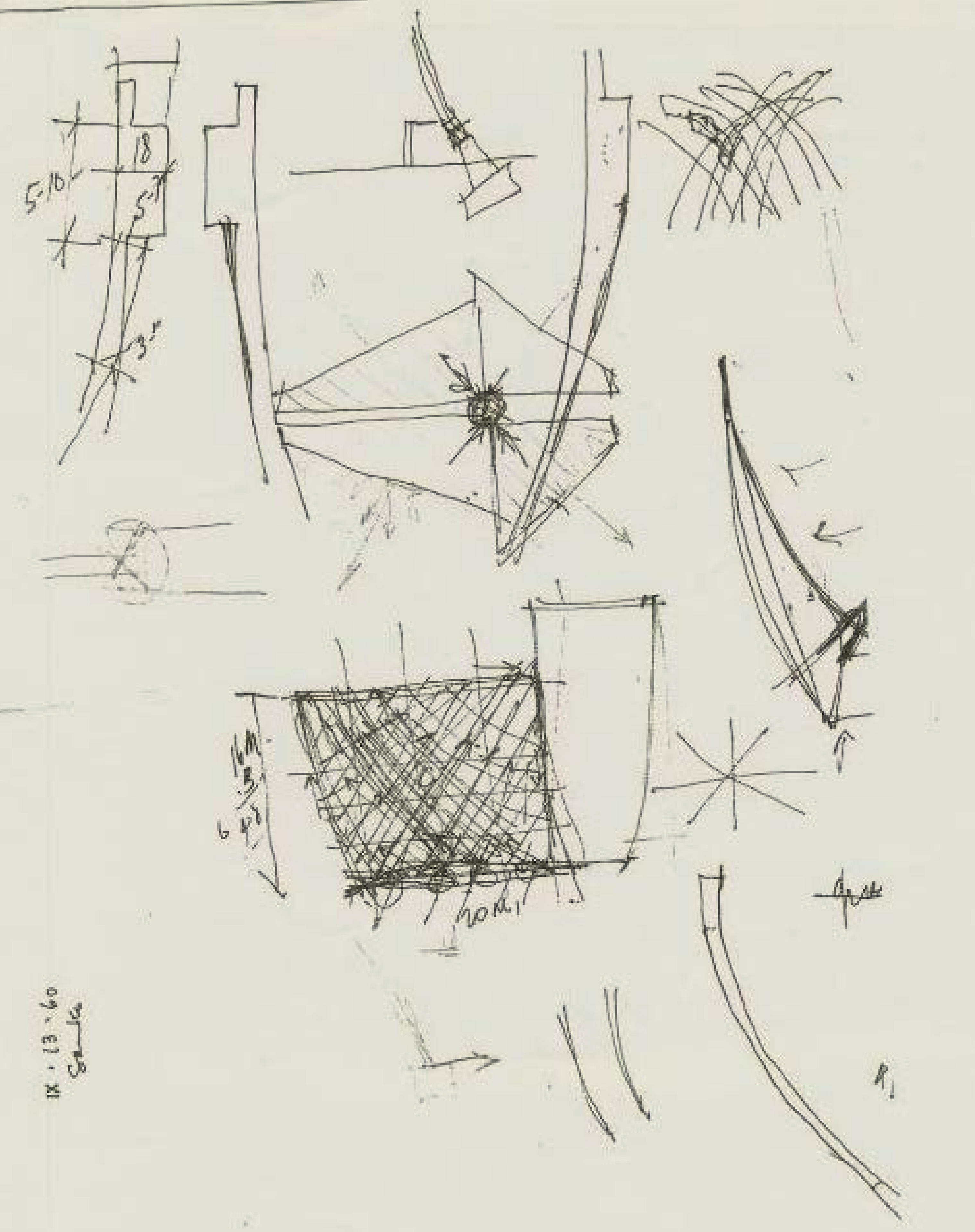


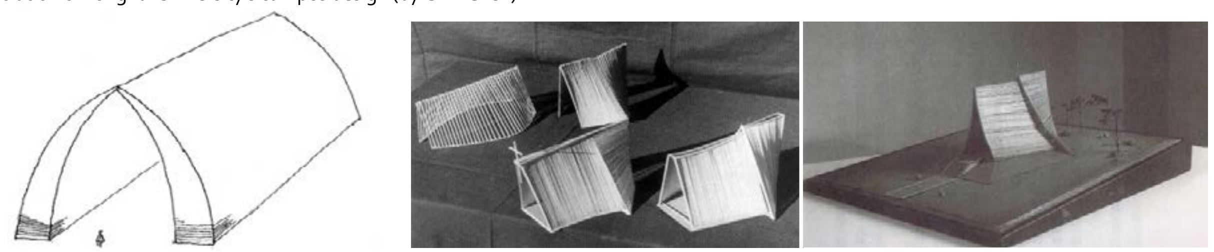
4. Structural Investigation and Seismic Evaluation of Henry Luce Memorial Chapel

Background and Documentary Research on Henry Luce Memorial Chapel

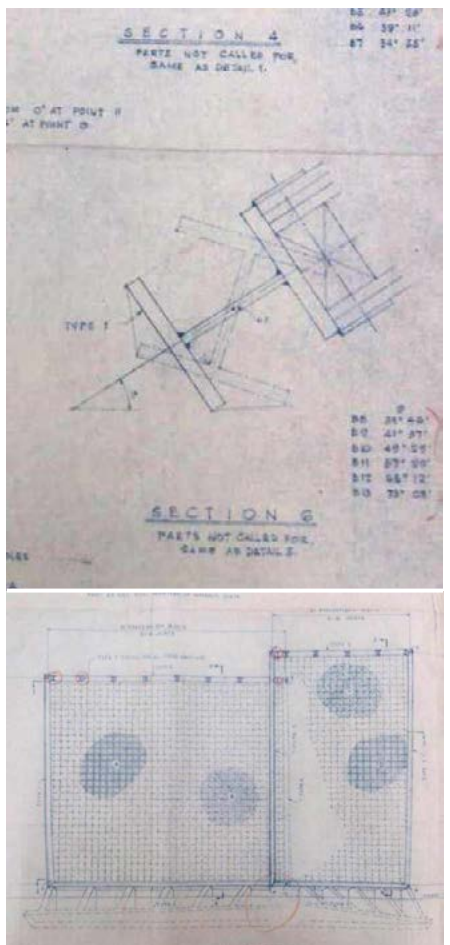
The Luce Chapel located at the heart of Tunghai University, Taiwan, was built in 1963. Through the combination of four hyperbolic shell walls made of reinforced concrete (RC), the chapel has an elegant contour, demonstrating an ingenious structural design. These hyperbolic walls do not only function as walls, but also serve as the pillars, beams and roofs of the building structure. As a perfect integration of space and structure, the Luce Chapel is not only an example of modernism in Taiwan, but also an outstanding modern architectural artwork worldwide.

To determine the structural system of Luce Chapel and its current condition requires thorough knowledge regarding the history of its design and construction background. Therefore, the original architectural graphics and photos taken during construction, related correspondence, and relevant documents were collected and analyzed for this research. In order to understand the background and logic behind the form of structure and its special features, further investigations were conducted. In addition, this study also digs into the dedications of H. S. Fong (鳳後三), the chief structural engineer of Henry Luce Memorial Chapel.

4.1 Illustration of Tunghai University's campus design (by C. K. Chen)



4.2 Preliminary design graphics and conceptual models of the chapel



4.3 Original design drawings of the chapel

1. The Design of Luce Chapel

In 1953, the United Board for Christian Colleges in China (UBCCC) decided to establish a Christian university in Taiwan and founded Tunghai University. After choosing the Dadu plateau in Xitun District of Taichung City as the site, the UBCCC invited I. M. Pei (貝聿銘), a renowned Chinese American architect, to supervise the overall campus design. The preliminary design was completed in New York with the participation of two young architects, C. K. Chen (陳其寬) and C. K. Chang (張肇康), who were responsible for the detailed design and subsequent project construction.

In the following year, Mr. C.K. Chen presented a Chinese ink drawing in front of the board to demonstrate his vision for the campus (Fig. 4.1). As displayed in Fig. 4.1, not only did he integrate the concept of Chinese garden art into the overall campus design, but he also designed a triangular chapel at the heart of the campus to symbolize the christian background of the university, expecting the chapel to be the center of campus life.

chapel design was finally initiated in 1956. During the design process, I. M. Pei proposed a design featuring a masonry pointed arch, which is typically used in Gothic architecture, while others suggested a vase-shaped design. By integrating the favorable features of these proposals, C. K. Chen developed a few models using wood strips, seeking an optimal scheme for the chapel design. In the end, the conoid structure was selected as the chapel's final design. The conoid structure comprises four hyperbolic walls as the major structural components, which forms a hexagonal space. With the windows being positioned along the centerline of the roof, natural light diffuses through the skylight, illuminating the entire space, magnifying the sacred and solemn atmosphere of the chapel.

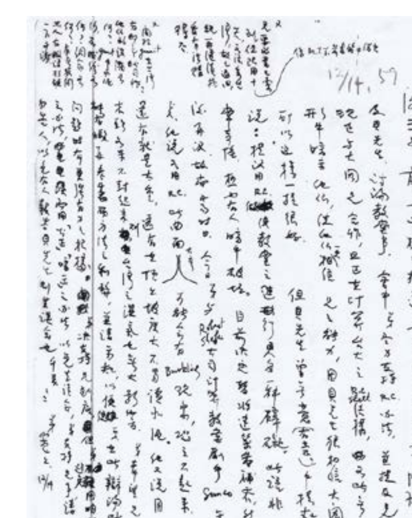
At the preliminary designing stage, wood strips were used to develop the conceptual models, and the models were found to resemble the shapes of wooden canoes; therefore, the architects adopted the idea of using wood as the major construction material. While Mr. C. K. Chang was supervising the construction of the campus project in Taiwan, I. M. Pei tasked him with investigating the method for wooden canoe fabrication in local shipyards. According to the graphics drawn by C. K. Chen in 1957, the original chapel design employed a three-planar wooden structure with purlins placed between the wood planes to form thin shells, which were reinforced with steel edges framing the circumference (Fig.4.3).

The curved steel edge frame was 18-meter long in total. To transport the steel frame to the construction site, the frame must be dissected into three sections, and each section was then to be reassembled by in-situ welding. By consulting D. H. Wu, a former classmate working in a shipyard in Keelung City, C. K. Chen realized that the steel edge frame was prone to distort when subjected to loading. At the same time, the project sponsor Henry Robinson III was intending to end the project as it came in with a high, and unsettled budget. Knowing the infeasibility of wooden structural design, C. K. Chen decided to abandon wood materials and seek for a RC solution. However, this also meant C.K. Chen needed to redesign the structure. Therefore he sought the consultation of a Taiwanese structural engineer, H. S. Fong on the possible RC solutions.

At first I.M. Pei did not agree with the idea of using RC structures for the chapel project. Fig.4.4 is a letter written by C. K. Chen to H. S. Fong in December 1959[5]. In the letter, Chen mentioned I. M. Pei's concern about a RC structural approach, but Chen expressed his determination to support the structural concept proposed by Fong. Therefore, Chen suggested finishing all architectural drawings before making any further discussions of the chapel project. To persuade I. M. Pei to trust in Fong's abilities to handle the project, Chen mentioned Fong's cooperation with the architect D. H. Wang[6] on the structural calculation of the RC shell roof of the Student Activity Center at National Taiwan University (Fig.4.5).

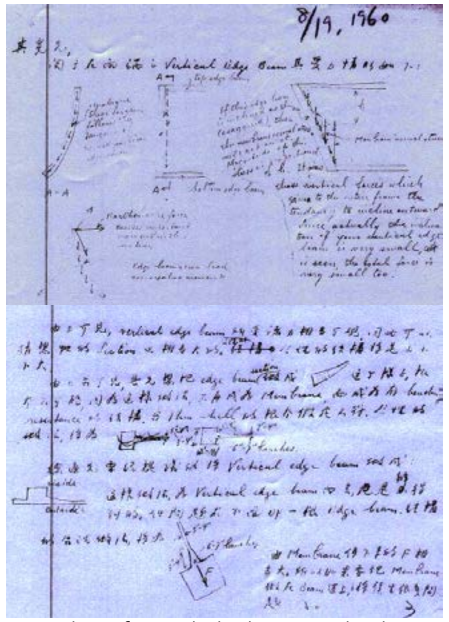
5. On December 14, 1959, C. K. Chen wrote to H. S. Fong:
Dear Fong, you must have received the last letter I sent. Last we ek, we had a meeting on the chapel project. Mr. Fenn, Priest, Fesgnon, and Pei all participated. In the meeting, I defended the RC approach and intentionally mentioned that you are now designing for a RC shell project in cooperation with D. H. Wang. Since Mr. Pei had a good relationship with Mr. Wang, I thought they would trust your abilities to handle the project by saying so. However, unexpectedly, Mr. Pei unintentionally (or intentionally?) indicated that applying a RC structure may impede the progress of the project. I think someone must have given him a negative viewpoint on the RC approach. Under the current circumstances, I decided to first complete all the architectural drawings before arranging a further discussion. This may take a while. You will need to wait patiently.
Today I had lunch with Sunco, who is an engineer in Roberts & Schaefer Company and now in charge of the chapel's structural calculation. He said because of the highly curved configuration of the chapel, RC shells are likely to buckle under heavy working loads. In addition, RC shells may also be too heavy to be erected, and pouring concrete mix to form the top parts of the shells can be problematic. He also mentioned that even if the steel edge frame is not used, the humid environment in Taiwan will pose a durability problem to the wood shells. Please re-evaluate the advantages and disadvantages of the structural scheme you proposed. I believe your effort will help us in defending our RC solution. I will stand up for you. However, in order to avoid possible misunderstanding, I would suggest the choice of using humble expressions (e.g., words like "suggesting" and "indicating") to present your ideas. Please don't mention the current situation to anyone. Mr. Pei might get the wrong idea on the matter from the others.

6. D. H. Wang is an architect of the Republic of China. After graduating from the Department of Architecture at the Univerisity of Cambridge, he attended a master program in architecture at Harvard University in 1941. During his study in Harvard, he was influenced by two o f his teachers, Walter Gropius and Mies Van Der Rohe, who were masters of modern architecture. Notably, two renowned architects, I. M. Pei and Philip Johnson, were his classmates at the time. Wang was the first Taiwanese architect who received modern Western education in architecture.



4.4 A letter written by C.K Chen to H. S. Fong (December 14, 1959)

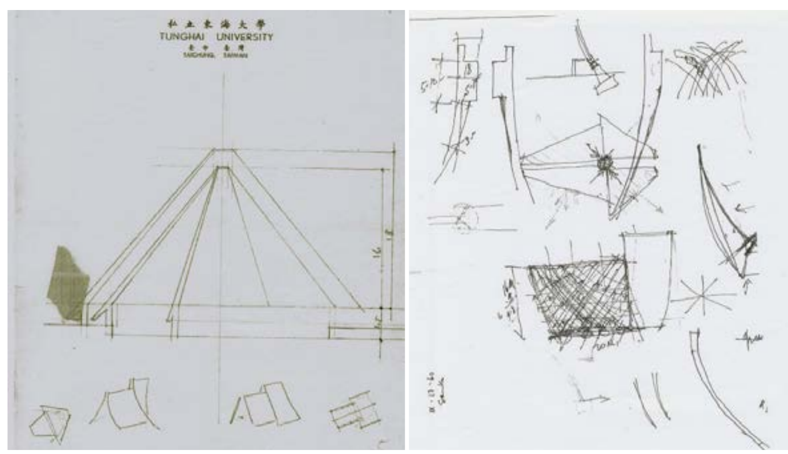
4.5 Student Activity Center at National Taiwan University (the design drawing was completed in 1961)



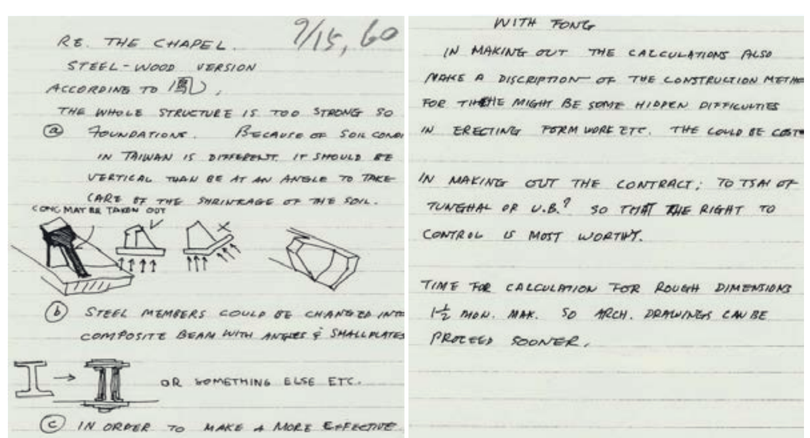
4.6 Analysis of vertical edge beams used in the chapel's thin shells (Aug. 19, 1960)

Moreover, C. K. Chen inquired H. S. Fong about gunite-related techniques (e.g., gunite equipment and cement mix recipes) in the letter, indicating his intention of applying gunite techniques[7] on the chapel project. According to relevant evidence, after the construction stages of framework and reinforcement work were completed, gunite was applied for an experimental purpose. However, a subsequent compression test revealed that the strength of the gunite samples did not satisfy the stipulated compressive strength (4000psi). Therefore, the grouting method was adopted instead.

In May 1960, Henry R. Luce came to Taiwan and visited the campus of Tunghai University in company with Y. E. Cai, the board chairman of Tunghai University. Reaffirming his determination of building the chapel, H. W. Luce requested I. M. Pei to re-evaluate the cost of the chapel project as he returned the Unite States. H. S. Fong started to take on the structural design and calculation of the chapel project and discussed with C. K. Chen through correspondence. Fig.4.6 demonstrates a stress analysis of the vertical edge beams and presents an investigation conducted to evaluate the validity of applying these edge beams and to determine the appropriate cross-sectional configurations for the beams. Through repeated discussions and modification, a RC chapel design gradually developed, which then became the prototype of today's Luce Chapel (Fig.4.7). However, in the meantime, a U.S. partner (likely a structure consulting firm) was still insisting on the wood-steel design. As shown in Fig.4.8, the letter from C. K. Chen to the U.S. partner indicates a discussion regarding the fundamental structure and the choice of wood shells, as well as a recommendation of replacing I-shaped steel beams with composite beams, which comprise steel angles and small steel plates. In addition, Chen estimated that the rough calculation of the structural components would take up to one and a half months.



4.7 Ideas of using lattice beams in Chen's sketch (Sept. 13, 1960)



RE. THE CHAPEL. 9/15, 60
STEEL-WOOD VERSION
ACCORDING TO 周,
THE WHOLE STRUCTURE IS TOO STRONG SO
ⓐ FOUNDATIONS. BECAUSE OF SOIL COND
IN TAIWAN IS DIFFERENT. IT SHOULD BE
VERTICAL THAN BE AT AN ANGLE TO TAKE
CARE OF THE SHRINKAGE OF THE SOIL.
CONC. MAY BE TAKEN OUT
ⓑ STEEL MEMBERS COULD BE CHANGED INTO
COMPOSITE BEAM WITH ANGLES & SMALL PLATES
OR SOMETHING ELSE ETC.
ⓒ IN ORDER TO MAKE A MORE EFFECTIVE
STRUCTURAL SKIN OUT OF THE 1" WOOD BOARD

WITH FONG
IN MAKING OUT THE CALCULATIONS ALSO
MAKE A DISCRIPTION OF THE CONSTRUCTION METHO
FOR THERE MIGHT BE SOME HIDDEN DIFFICULTIES
IN ERECTING FORM WORK ETC. THE COULD BE COST

IN MAKING OUT THE CONTRACT; TO TSAI OF
TUNGHAI OR U.B.? SO THAT THE RIGHT TO
CONTROL IS MOST WORTHY.

TIME FOR CALCULATION FOR ROUGH DIMENSIONS
1½ MON. MAX. SO ARCH. DRAWINGS CAN BE
PROCEED SOONER.

4.8 Discussion with the US partner regarding the wood-steel version of the chapel design (Sept. 15, 1960)

7. Gunite is a construction technique for stabilizing slopes through spraying cement or concrete over the receiving surface by using compressed air. Gunite can be applied through dry-mix or wet-mix methods. In the dry-mix method, a dry sand-cement mixture is blown out of a hose by compressed air. Then, water is injected at the nozzle to hydrate the mixture. The wet-mix method spreads a ready-mix of sand, cement and water onto the receiving surface. The term gunite specifically refers to cement mixtures, whereas shotcrete for concrete mixtures.

8. Henry Robinson Luce was the founder of the American magazines Time and Life. To provide a venue for evangelism, he sponsored the Luce Chapel project in memory of his father Henry Winters Luce.

Due to the aforementioned reasons, the Luce Chapel project was once put on hold. On April 25, 1961, the board chairmen of Tunghai University, Mr. Y. E. Cai wrote a letter to the sponsor, H. R. Luce. In the letter, Cai expressed his faith in the team having C. K. Chen as the architect, H. S. Fong as the structural engineer, and Guanyuan Construction as the local construction company. Cai also reassured Mr. Luce that the team could satisfy his expectation to construct a spectacular chapel. In response, Mr. Luce granted 150,000 USD to sponsor the chapel's construction. Soon afterwards, H. S. Fong completed the structural calculation, and all the completed graphics (e.g., construction, structural, and detailed drawings) were sent to I. M. Pei in New York for a final evaluation. According to C. K. Chen's recollection, "a young German structural engineer working in a cooperative engineering consulting firm strongly opposed Fong's structural design, whereas the company's chief executive considered the design to be feasible. In this situation, Mr. Pei was unsure of the correct course of action and invited Mr. Fong to New York to explain the calculation model. I also traveled to New York with Fong and stayed for 2 weeks to re-evaluate the feasibility of the structural design. To our surprise, the German engineer quitted his position on the third week, and thus no one else questioned the design. Since the owner of the consulting company approved the design, Mr. Pei had to agree with Fong's calculation. When the chapel's construction was finally completed, Mr. Pei especially credited Mr. Fong in the inauguration ceremony." (Excerpted from My affinity with Tunghai, The Wind of Tunghai 我的東海因緣． 東海風)

Table 4-1 Timeline of designing Luce Chapel

1954.02	I. M. Pei visited Taiwan to inspect the chapel site on the Dadu plateau for the first time.
1954.	C. K. Chen demonstrated his vision for the campus landscape by using a traditional Chinese ink drawing.
1956.	C. K. Chen won the first place in the Youth Center Building Design Contest hosted by Architectural Forum.
1956.07	I. M. Pei visited Taiwan again.
1956.08	I. M. Pei, C. K. Chen, and C. K. Chang discussed about the chapel design at Katona's home. (Masonry Gothic archàHexagonal wooden canoe modelàC. K. Chang's investigation on the method of fabricating wooden canoes)
1957.03	C. K. Chen sequentially published his drawings related to the chapel project (i.e., building plans, internal perspective view, color ink paintings) and the chapel model on Architectural Forum (1957.03, 08) and Architectural Record (1957.08).
1957.09	C. K. Chen paid his first visit to Taiwan.
1958–1959	The project was suspended because of an excessively high budget of the original wood-steel design.
1959.12.14	C. K. Chen expressed his support for H. S. Fong's RC structural concept in a letter written to Fong.
1960.05.22	H. R. Luce visited Tunghai University.
1960.08.19	H. S. Hong and C. K. Chen discussed problems regarding the application of thin-shell structures.
1960.09.13	C. K. Chen revealed his idea of using lattice beams in a hand sketch.
1960.09.15	One of the involved parties from the US (likely a structure consulting firm) brought out the wood-steel version design in a letter.
1961.04.25	Y. E. Cai wrote to H. R. Luce, and highly recommended the team for architectural, structural design, and the construction company of the chapel project. In addition, he successfully obtained an 150,000 USD sponsorship from H. R. Luce (the actual construction cost 100,000 USD).
1962.09.27	Discussion on the height of each construction level
1962.11.01	The chapel construction started.

4.9 Eduardo Catalano House in Raleigh (source: http://goodnightraleigh.com/2010/02/the-passing-of-a-legend-an-opportunity-lost/)

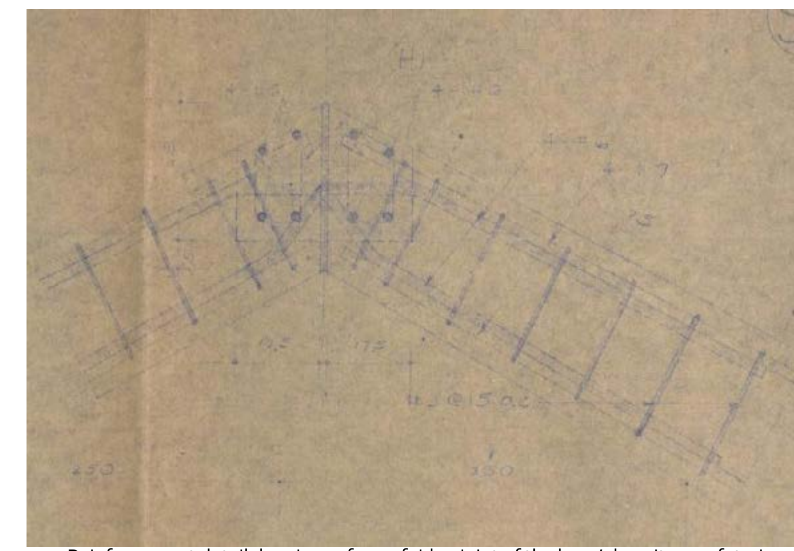
4.10 Current state of the old architecture department building

4.11 Current status of the old music department building

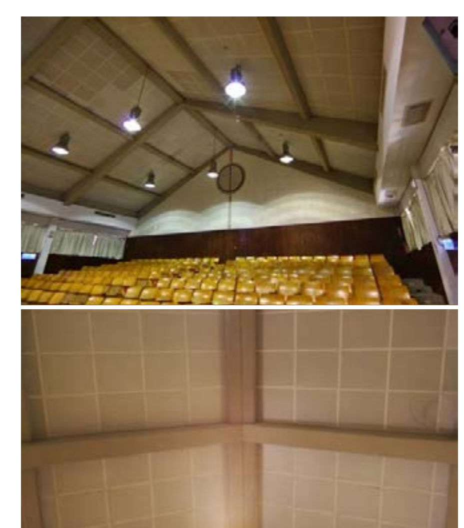
2. Thin Shells and Pin Connections

The design of Luce Chapel was influenced by the designers' conceptual ideas, but most importantly by an architectural trend of thin hyperbolic shells. This trend in the architectural circle caught the attention of C. K. Chen. As he recollected, "two South African architects Catalano & Horicio Camilo were teaching at North Carolina and conducted various tests related to thin shell and membrane structures. They literally started the trend of thin-shell structures. I particularly travelled to North Carolina to visit them. They told me that the concept of such hyperbolic shells was originally developed by German mathematicians. German engineers discovered concrete as a workable material for shell shape structures. In South Africa, such practices were extensively adopted in construction projects. Beside thin shells, membranes can also be constructed using the same approach. Moreover, the US on-trend inflatable structures and even dome structures were both developed on the base of the thin shell and membrane construction practices. I was also amazed by hyperbolic membrane structures. Therefore, I thought about structuring the chapel with just RC thin shells or membranes without using beams and columns. The others also thought this was a novel direction in design; therefore, when I decided to employ this design idea, Mr. Pei also agreed." (Excerpted from My affinity with Tunghai, The Wind of Tunghai 我的東海因緣． 東海風)
The old architecture department building (completed in Oct. 1961) and the music department building (completed in Feb. 1963) on the campus of Tunghai University are two other thin-shell structures designed by C. K. Chen. At that time, Chen took the position of the university's first dean of the Department of Architecture. In addition to overseeing the campus construction, he also pushed the chapel project forward and sought structural solutions for the project. Before the commencement of the chapel's construction, various experiments were conducted on the sites of the abovementioned two buildings to evaluate the validity of relevant novel construction techniques. These experiments were not only to test the abilities of local construction companies at constructing thin-shell structures, but also provide opportunities for these companies to gain valuable experiences in hyperbolic structural construction.
The old architecture department building consists of two rows of RC umbrella shells with a row spacing of 4.5 m. As shown in Fig.4.10, the masonry walls along the narrow side of the building separate the building's inner space, and a large area of glass on the side walls ensures adequate lighting and ventilation. To satisfy the functional requirements of the department, the building was designed to enable flexible inner space usage. This building's construction only took a summer to complete, and was the first thin-shell structure in Taiwan.
The classrooms and practice rooms of the old music department building were jointed to form a U shape structure, and enclosed a small courtyard with a small outdoor performance hall. The building complex resembles traditional Chinese courtyard houses. Unlike the aforementioned architecture department building, the shells of the building had a particular 45-degree curvature, conveying a distinct side image.
Regarding the chapel's roof joint design, C. K. Chen recalled that "the foundations of the chapel were very large because they were designed to support the above hyperbolic shells, which are thin at the top but gradually grow thicker as they descend, leaving heavy RC walls at the bottom structures. In addition, lattice beams added additional weight. A total of six joints were allocated along the roof ridge, and the reinforcing bars in the joints were arranged in an overlapping manner to increase flexibility, which would avoid the walls from bending or breaking."(Excerpted fromMy affinity with Tunghai, The Wind of Tunghai 我的東海因緣． 東海風)
Before the construction of the chapel took place, the validity of the fabricated roof joints (also called "live joints" by C. K. Chen) was tested in the construction of a cafeteria in boys' dormitory (Fig.4.12) and Ming-Shen Auditorium (Fig.4.13, completed in Jun. 1959). The structural designs of these two buildings were also by H. S. Fong. Although the structural system is now invisible in appearance, three connecting points actually locate separately at the bottom of the side columns and the top of the beams according to the reinforcement demonstration of the two buildings (Fig.4.14 & Fig.4.15). The reinforcing bars were placed in an overlapping manner to form a pin connection (i.e., three-hinged arch). Theoretically, when subjected to working loads, such connections allow partial damage and rotation, thereby releasing the bending forces at the ends of the beam. Consequently, the beam's cross-sectional size decreased, which led to the decrease of material cost. This type of pin connections was then modified and used in the construction of the chapel (elaborated in Section 2.1).

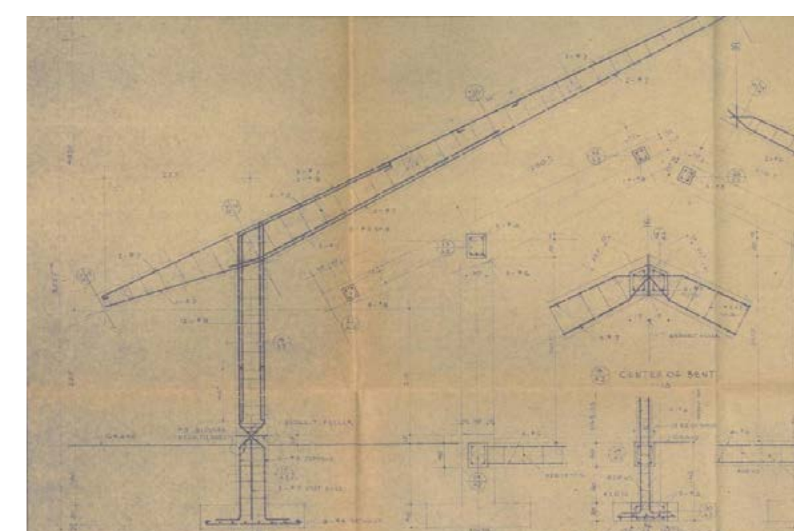
4.12 Current state of the cafeteria in boys' dormitory at Tunghai University



4.14 Reinforcement detail drawings of a roof ridge joint of the boys' dormitory cafeteria

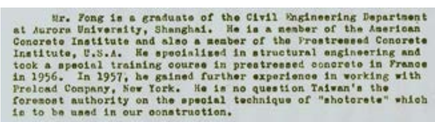


4.13 Current state of Ming-Shen Auditorium in Tunghai University



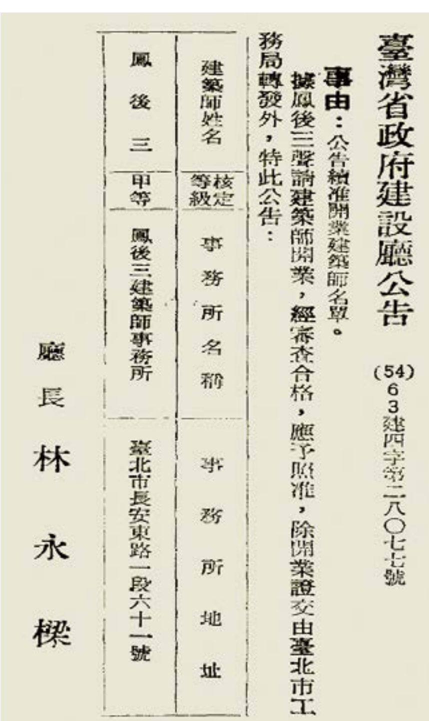
4.15 Reinforcement detail drawings of Ming-Shen Auditorium building


4.16 Structural engineer: H. S. Fong


Mr. Fong is a graduate of the Civil Engineering Department at Aurora University, Shanghai. He is a member of the American Concrete Institute and also a member of the Prestressed Concrete Institute, U.S.A. He specialized in structural engineering and took a special training course in prestressed concrete in France in 1956. In 1957, he gained further experience in working with Preload Company, New York. He is no question Taiwan's the foremost authority on the special technique of "shotcrete" which is to be used in our construction.

4.17 A letter from Y. E. Cai to H. R. Luce (Apr. 25, 1961)


4.18 Roof project of a military stadium (Completed on Dec. 26, 1952)


臺灣省政府建設廳公告 (54)6 3建四字第二八〇七七號

事由：公告核准開業建築師名單。

據鳳後三聲請建築師開業，經審查合格，應予照准，除開業證交由臺北市工務局轉發外，特此公告：

建築師姓名	核定等級	事務所名稱	事務所地址
鳳後三	甲等	鳳後三建築師事務所	臺北市長安東路一段六十一號

廳長 林永樑

4.19 An announcement issued by Reconstruction Department of Taiwan Provincial Government

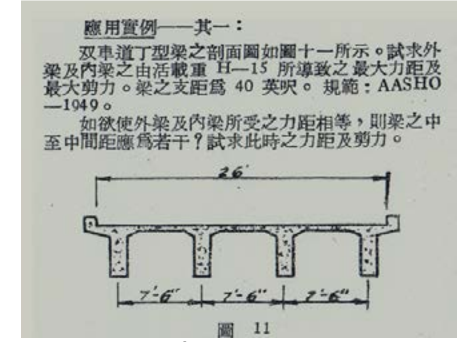
3. Structural Engineer: H. S. Fong

H. S. Fong (Feb. 8, 1919–Jan. 1983) contributed tremendously from the structural calculation to the actual construction of the Luce Chapel. After the chapel project, Fong went to work with I. M. Pei in New York upon the recommendation of C. K. Chen. He started his career in the United States thereafter, and died in Chicago in 1983.

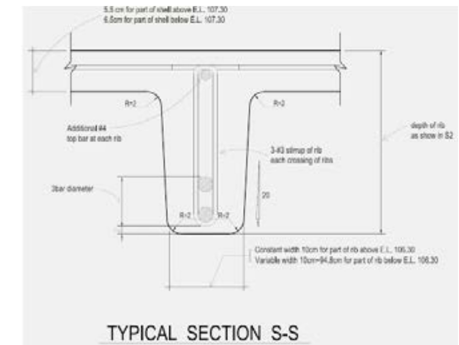
The available information regarding H. S. Fong is very limited. His education and career background can only be inferred from the letter written by Y. E. Cai to H. R. Luce (Fig.4.17) and was thus summarized as the following:

- Bachelor of Arts from the Civil Engineering Department at Aurora University in Shanghai, China
- A member of American Concrete Institute
- A member of Prestressed Concrete Institute, the United States.
- Participated in a special training program on prestressed concrete in France in 1956.
- Worked with Preload Inc. in New York and gained further practical experiences in 1957.
- Well known as Taiwan's leading expert in the shotcrete technique, which was used in the Luce Chapel project.

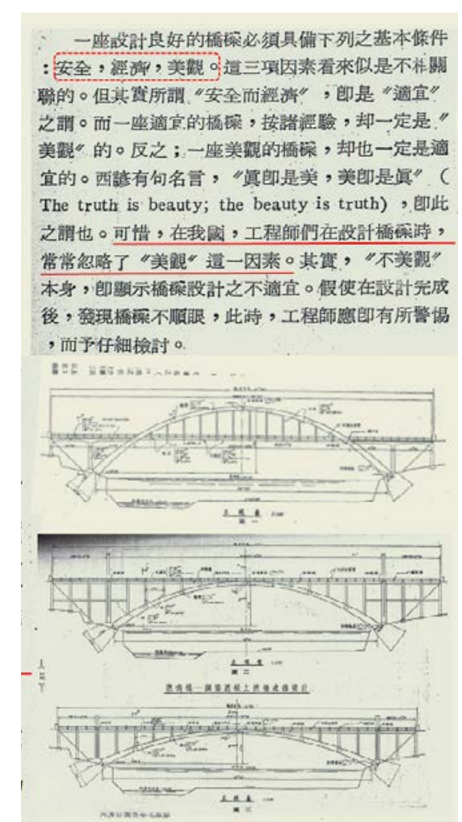
Moreover, H. S. Fong sequentially published 13 articles in Taiwan Highway Engineering between 1952 and 1954. According to these magazine articles and another news article which reported Fong's participation in a roof project for a military stadium (Fig.4.18), Fong once held an engineer position in the Directorate General of Highways. In 1965, Fong sought related authorities to apply his architect license (Fig.4.19) before setting his office in Taipei.



4.20 An example of calculating a T-shaped continuous beam (Mar. 1953)



4.21 The section of a typical non-uniformed lattice beam used in the chapel project



4.22 Excerption from the article Discussion on the Possibility of Applying a RC Arch Form in the Jiuluming Bridge Design (Dec. 1953)

According to Fong's articles published in a highway-engineering magazine (Table 4-2), Fong had thorough investigations on non-uniformed continuous beams and T-shaped beams before he participated in the Luce Chapel project (1962). His knowledge on these beams structures strongly influenced the structural concept and design of the chapel. Since Taiwan was prone to earthquakes and typhoons, Fong also tried to resolve these factors in his design.

Table4-2 Fong's articles published in the Highway Engineering Magazine (台灣公路工程月刊) and other publications (1952–1954)

民41.11	1:1	介紹幾種能適用於橋梁建築的鋁合金及應用實例	頁8-11	譯
民41.11	1:1	集中荷重在不加勁式單孔懸橋主索所發生最大撓曲度公式之誘導	頁14-15	
民42.01	1:3	丁型梁經濟高度之較合理公式	頁12-13	
民42.02	1:4	幾張有助于丁型設計的圖表	頁3-4	
民42.03	1:5	丁型樑之"公佈係數"的一般公式	頁10-14	
民42.05	1:7	用重疊法計算變矩連續梁-1	頁1-7	
民42.06	1:8	用重疊法計算變矩連續梁-2	頁1-5	
民42.07	1:9	丁型樑設計圖表	頁6-10	
民42.09	1:11	美國公路橋樑之實際標準及規範-1	頁11-13	譯
民42.10	1:12	美國公路橋樑之實際標準及規範-2	頁18-21	譯
民42.12	2:2	論鹿鳴橋建成鋼筋混凝土拱橋之可能性	頁9-12	
民42.12	2:2	鋼筋混凝土拱橋雜談	頁20	譯
民43.06	2:8	美國公路橋樑之實際標準及規範-3	頁12-14	譯
民46.11	6:1	預力混凝土的鋼線問題	頁27-29	演講

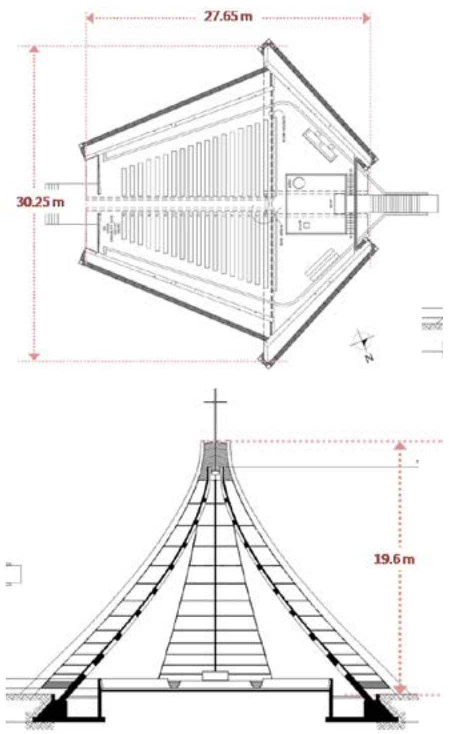
Fong published the article Discussion on the Possibility of Applying a RC Arch Form in the Jiuluming Bridge Design in Dec. 1953. This article presents Fong's philosophy on engineering, and unveils his ambition as a qualified structural engineer.

He specifically insisted that a good structural design must addresses safety, economics, and aesthetics. He also noted that engineers in Taiwan often neglected aesthetic factors, thereby leading to inappropriate designs.

According to the Chinese edition of the book Conversations with I.M. Pei (Boehm, 2003), Pei highly appraised Fong's contribution on the structural design of Luce Chapel, by saying, "I cannot complete the design of the chapel without Fong's help…I think Fong's structural design is a great success. The designed shells have a large load-carrying capacity and can resist loads induced by typhoons and earthquakes." (Conversations with I.M. Pei)

Analysis of the Structural System of Luce Chapel

The Luce Chapel is a RC structure which intentionally bridges the East-West dichotomy (Fig.2-1). The main entrance at the front of the chapel faces east, and the back door points toward west. The plan of the chapel displays a hexagon building with unequal side lengths. Moreover, the chapel is symmetrical along the east–west axis (the major axis), and the largest breadth at the ground level along the north–south direction is 30.25 m. The elevation view of the chapel exhibits hyperbolic paraboloid planes, and the chapel tapers from a wide bottom to a narrow top.



4.23 Plan and cross-sectional views of Luce Chapel

1. Structural Concept and Load-Carrying Mechanism

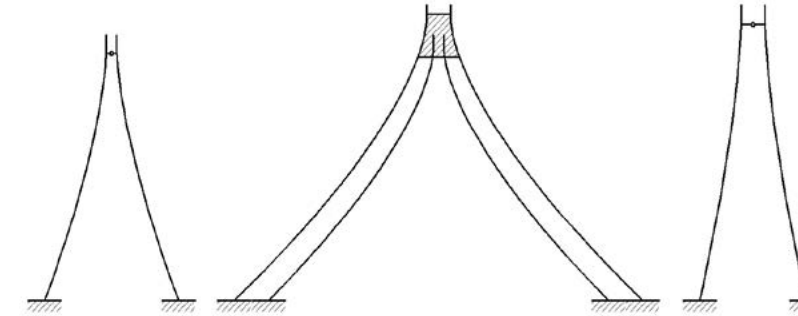
Structurally, Luce Chapel was designed to apply RC lattice-beam grids and slabs as the primary structural components to create four hyperbolic surface shells, which are arranged symmetrically along the chapel's major axis (Fig.4.24). In the lattice-beam grid system, each beam is narrow at the top and wide at the bottom and intersects with adjacent beams at a skew angle (Fig.4.25). Furthermore, the two front shells and two rear shells were separately joined using pin joints at particular positions along the ridgeline (Fig.4.26), and all four shells were rigidly connected using a shear wall at the conjunction (Fig.4.27).

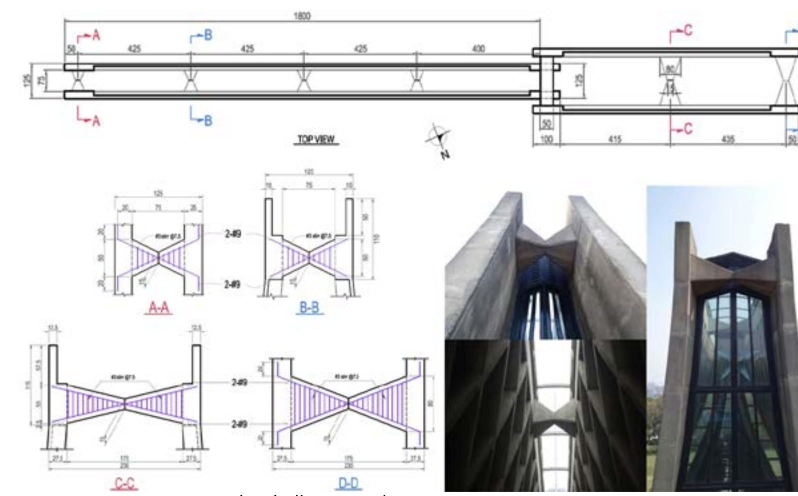

4.24 Side view of the hyperbolic shells


4.25 Lattice beams with varying cross sections


4.26 Pin connections


4.27 Fixed connection

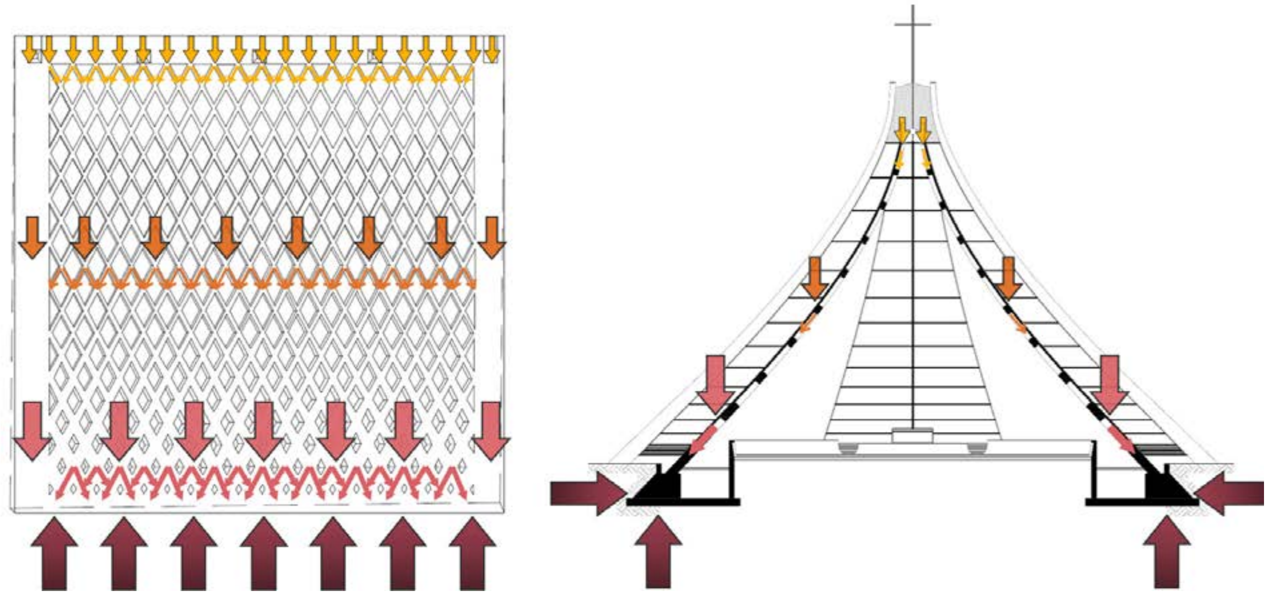

(a) Front arch (b) Middle arch (C) Rear arch
4.28 Schematic models of the edge-column arches



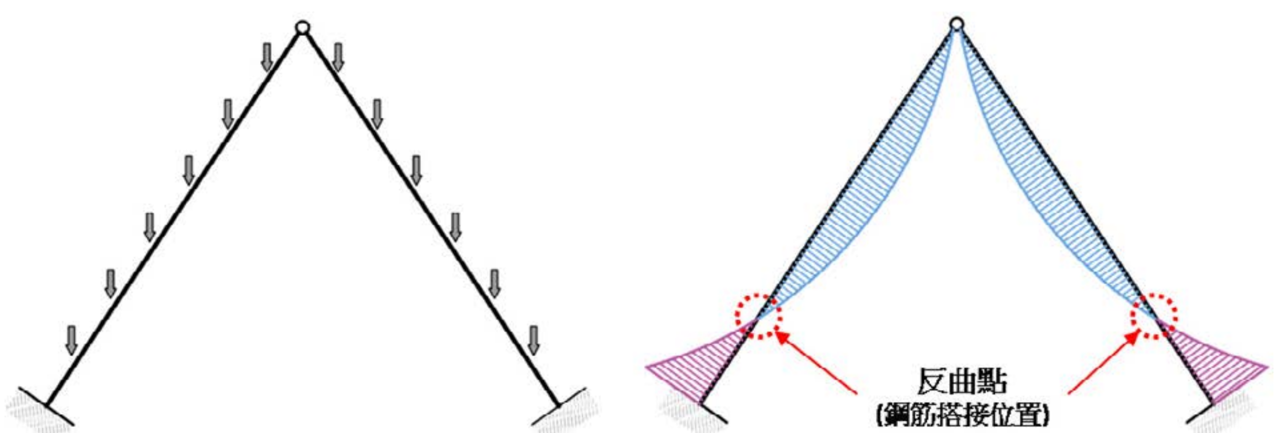
4.29 Pin connections at the shells' top ends

The chapel's structural system consists of three primary components: (1) the shell slabs and components around the shell edges (i.e., edge beams and columns in the vertical and horizontal directions, respectively), (2) lattice-beam grids, and (3) pin and fixed connections. The edge columns were designed to form three inverted arches along the major axis of the chapel (Fig.4.28), and serve as the most substantial components in resisting tensile forces and bends. The two edge columns of the front and rear arch are pin connected to each other at the top ends, and the bottom ends of the beams are rigidly attached to the foundations (Fig.4.28). The middle arch comprises two sub-arches, in which a deep beam was designed to hold the top ends of the four edge columns together, and their bottom ends were rigidly joined to the corresponding foundations. Additionally, the lattice-beam grids were designed to carry tensile forces and transfer the horizontal forces to the sides of the chapel.

(Fig.4.29) displays detail drawings of the rooftop connections. These drawings demonstrate four #9 reinforcing bars overlapping at the center of the connecting points. In addition, #3 stirrups were applied to convey an image of two truncated pyramids connected with pin joints. When subjected to working loads, the connecting points enable partial damage and rotation, releasing the bending moments of the connected shells. C. K. Chen called these connecting points "live joints". The connecting ends of the joints bear no bending moments; therefore they were designed to be relatively thin along the ridgeline. Moreover, due to the great shear forces at the conjunction of the four shells, a deep beam was employed for the resistance of the forces.



4.30 Schematic diagram of the transferring pattern for vertical loads (self-weight)



4.31 Schematic moment diagram of the chapel's structure under vertical loading

I.Vertical Load Transfer Mechanism

When the chapel structure is subjected to a vertical load (i.e., self-weight), the shell slabs, lattice-beam grids, and edge columns together serve as a primary path for transferring vertical load (Fig.4.30). Specifically, the weight of the rooftop windows and shells is transferred through the slabs to the lattice-beam grids and edge columns and then to the foundations and underlying soil.

(Fig.4.31) demonstrates the schematic moment diagram of the chapel bearing its self-weight. As displayed, the two shell planes were assumed to be pin connected, suggesting zero moments at the connected ends of the shells. Moreover, above the inflection point, each shell carries positive bending moments (i.e., the concave part of shells within the chapel), and the maximal moment occurs at the middle point between the pin connection and inflection points. Conversely, negative bending moments (i.e., the concave shells extended outward) occur below the inspection point, and the maximal moment is at the shell's footing.

II. Overall Structural Performance of Luce Chapel

(Fig.4.32~Fig.4.35) demonstrate the simulation analysis of the chapel's structure under vertical loadings. Details regarding the development and assumptions based on the simulation models are noted in Section 5.1. According to the analytic results, the overall structural performance of the chapel is summarized as follows:

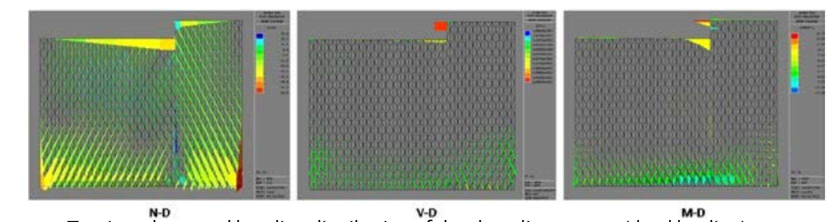
(1) The edge columns of the front and rear arches and the edge beams along the ridgeline had considerable large tension forces.

(2) The maximal shear force occurred at the outer side of the shear wall when the four shells connect at the middle arch.

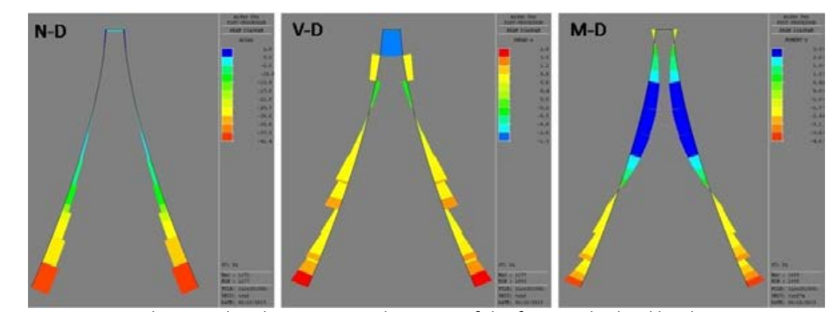
(3) The second largest shear force occurred at the bottom areas of the lattice-beam grids.

(4) The maximal bending moment of each lattice beam occurred at the bottom of the beam, and the beams closer to the front–back shell conjunction had larger maximal bending moment values.

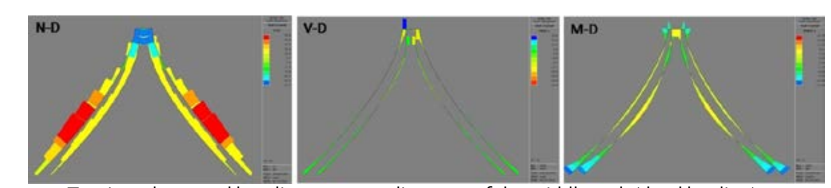
(5) Having compared with the lattice beams, the edge columns had larger positive bending moments.



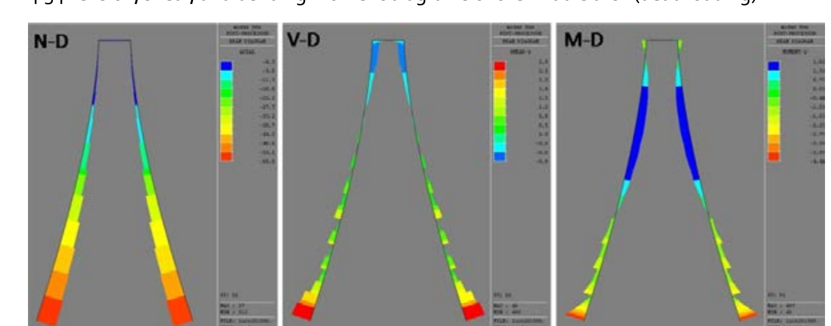
4.32 Tension, shear, and bending distribution of the chapel's structure (dead loading)



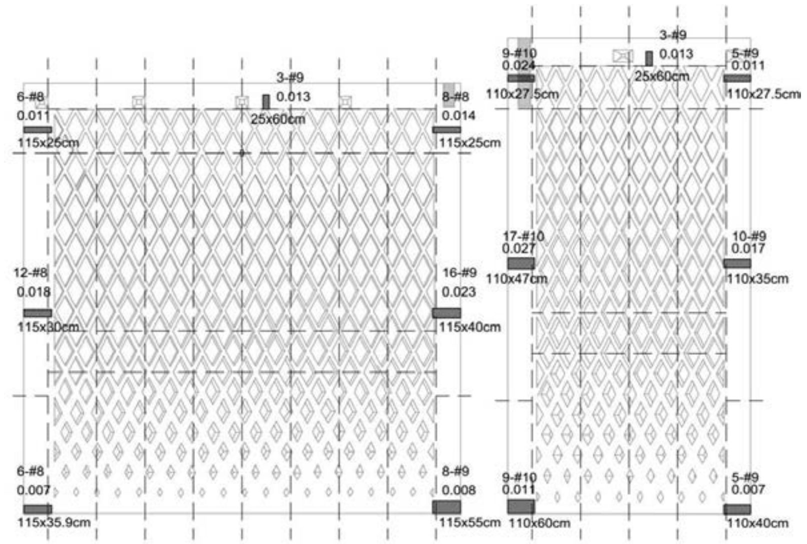
4.33 Tension, shear, and ending moment diagrams of the front arch (dead loading)



4.34 Tension, shear, and bending moment diagrams of the middle arch (dead loading)



4.35Tension, shear, and bending moment diagrams of the rear arch (dead loading)



4.36 Cross-sectional dimensions of the edge beams and the reinforcement arrangement (digitally regenerated structural diagrams, CHS2, CHS5, and CHS6)

4.37 Construction picture of an edge column (the lower section)

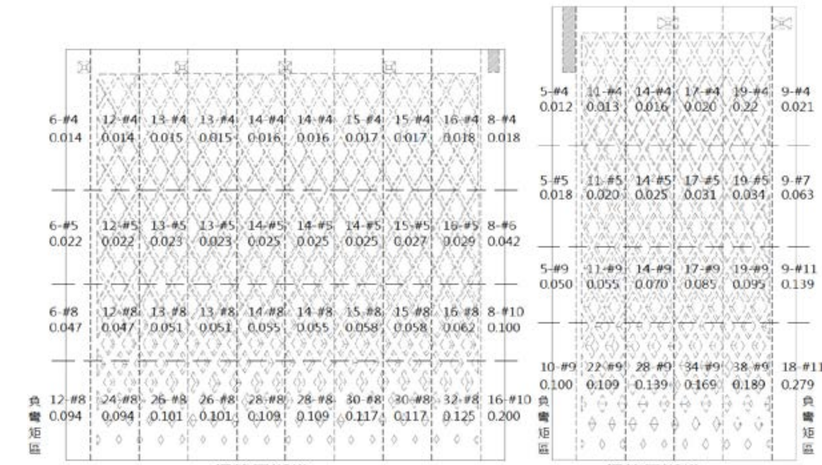
4.38 Construction picture of an edge beam at the rooftop level

2. Investigation of the Reinforcement Designs of the Structural Components

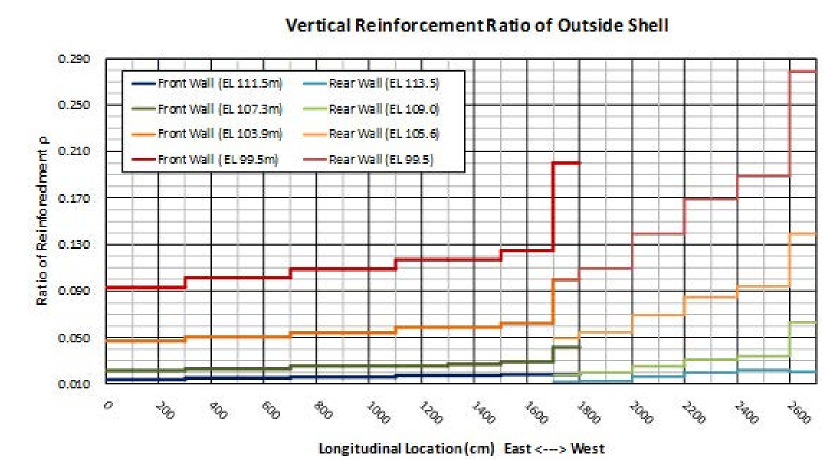
To determine the behaviors of the three major components (i.e., the edge beams and columns, shell slabs, and lattice-beam grids) of the structure, this study investigated the reinforcement designs of the components.

I. Reinforcement Designs of the Edge Beams and Columns

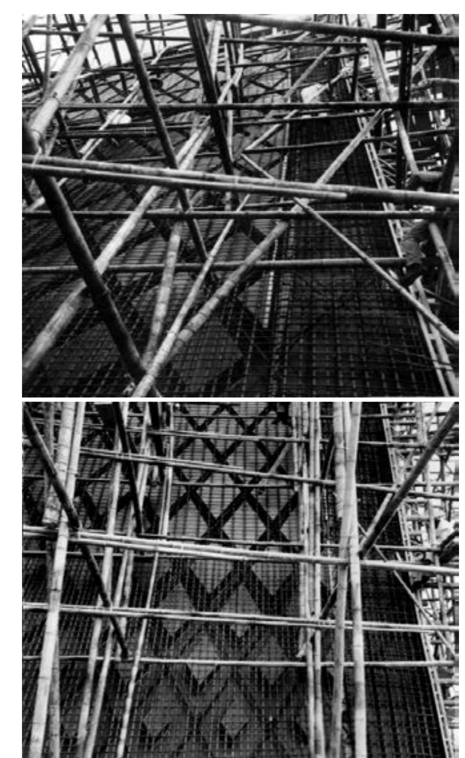
Each of the edge columns consists of three sections, which have distinct cross-sectional areas, thereby creating a tapered configuration with a thin top and a thick bottom. This design accommodates the vertical loading condition of the beams. Moreover, because the beams' middle sections are in the maximal positive bending moment zone, a considerable amount of reinforcing bars were placed at the inner side of these sections. The beams' lower sections were designed to have adequate reinforcing bars at the outer sides to resist negative bending moments. This reinforcement design conforms to the moment distribution induced by the vertical load. Furthermore, regarding the edge beams along the ridgeline, three #9 reinforcing bars were placed at each of the tension and compression sides of the beams, and #3 stirrups were employed with a spacing of 20-cm (Fig. 2-14).



4.39 Vertical reinforcement arrangement and reinforcement ratio of the shell slabs (digitally regenerated structural diagrams, CHS5 and CHS6)



4.40 Vertical reinforcement ratio of the shell slabs (digitally regenerated structural diagrams, CHS5 and CHS6)

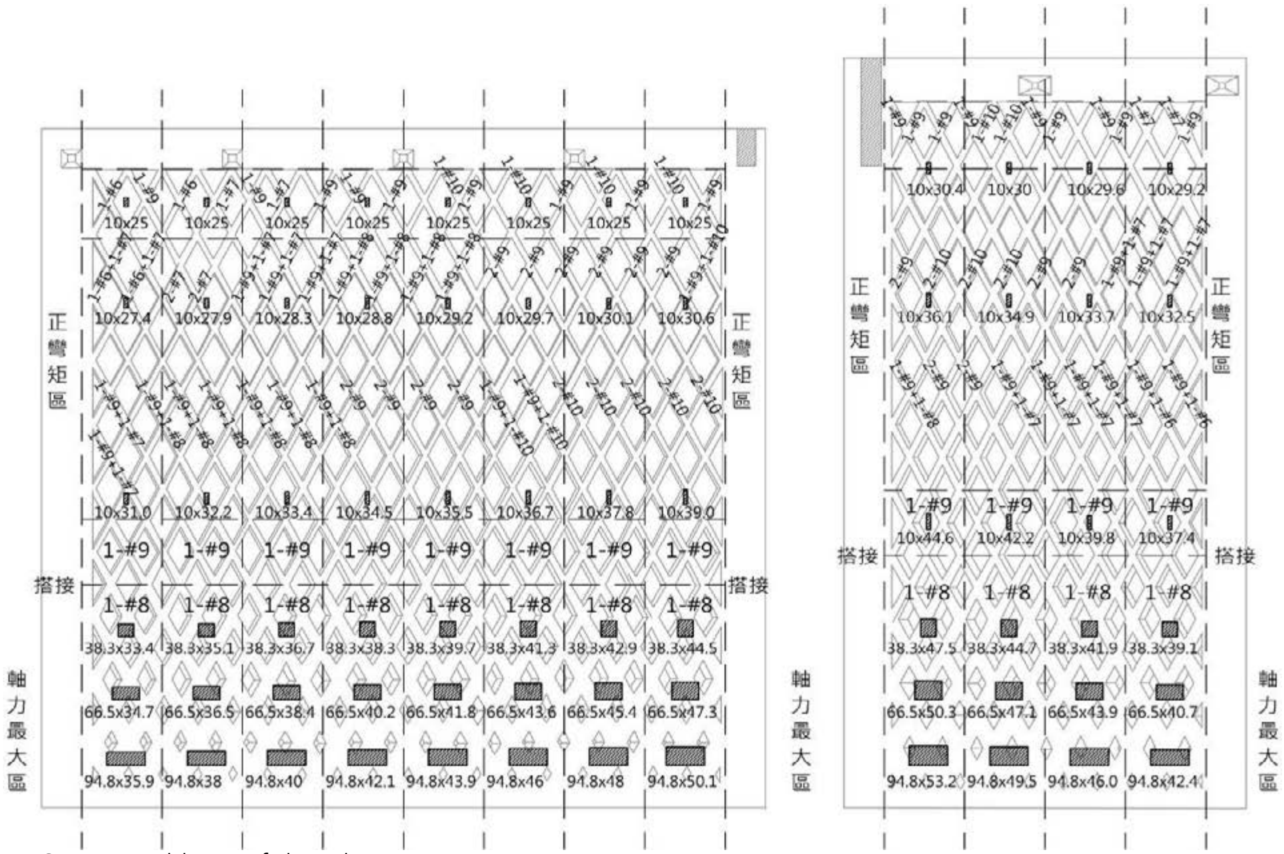


4.41 Construction pictures of the outer sides of the shell slabs (# 3 horizontal reinforcing bars were placed with a 10-cm spacing)

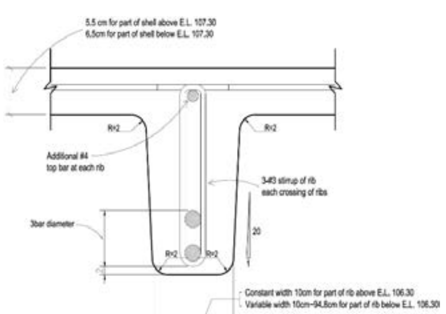
II. Reinforcement Designs of the Shell Slabs

According to the reinforcement designs of the slabs of the four shells, the primary reinforcing bars were placed vertically, and the bars' numbers were varied in an ascending order from the top to the bottom of the shells (#4–#11) in an attempt to accommodate the bending moment distribution pattern in the slabs. According to the reinforcing bar size and number placement, four distinct placement patterns were present along the slabs' vertical axis, and the reinforcing bars' total area reached the maximum at the slabs' bottom. In addition, the secondary reinforcing bars were placed horizontally at a 10-cm spacing, and the reinforcement ratio was thus 0.013.

Moreover, according to the original reinforcement design, the reinforcing bars of the front shell slabs were arranged in a particular pattern, in which the reinforcement along the chapel's major axis increased gradually from the shells' east to west ends. The same reinforcement placement pattern was presented in the rear shell slabs. Details and discussions on the vertical reinforcement arrangement of the four shell slabs and reinforcing bar detection procedure are clarified in Section 4.2.



4.42 Cross-sectional drawing of a lattice beam



4.43 Construction picture of lattice beams

4.44 Cross-sectional dimensions and reinforcement ratios of the lattice beams (digitally regenerated structural diagrams, CHS2 and CHS)

III. Reinforcement Designs of the Lattice Beams

The shells, which consist of the lattice-beam grids and slabs at the inner and outer sides, respectively, were designed to have various thicknesses; specifically, the shells grow thicker as they descend from the top to the bottom. Above the elevation of 106.3 m, the width of each single lattice beam is 10 cm, whereas below this elevation, the width increases gradually and reaches 94.8 cm at the bottom. This design is to coordinate the tensile force, which grows gradually from the top to the bottom of the beams.

The reinforcement placement of each lattice beam varies along the beam's longitudinal direction. According to the distinct reinforcement arrangements of the lattice beam, the beam can be divided into four sections from the top (Section 1) to the bottom (Section 4) of the beams (Fig.2-20). In a lattice beam, a single #9 reinforcing bar was applied through Sections 2 and 3, and an additional reinforcing bar (#7–#10) was added to Section 2 to increase the section's moment-resisting capacity. At Section 4, a single #8 reinforcing bar was applied, and the boundary between the Sections 3 and 4 was set at the beam's inflection point, which conforms to the common reinforcement practices.

4.45 Application of an aerial lift truck to inspect the chapel's outer surfaces

4.46 Mobile scaffold (the elevation of 3–7 m)

4.47 Temporary framework (the elevation was more than 7 m)

4.48 Steel tubes and slipknots of the framework

Investigation on the Current State of the Luce Chapel

Ever since the completion of its construction in 1964, the Luce Chapel has been continuously maintained for more than 50 years. Most of the previous repair and maintenance focused on sustaining the rooftop windows, floor, and wooden furniture in addition to cleansing the tiles attached to the surface of the shell structure. However, after the 921 earthquake in 1999, a repairing project was conducted by applying a crack perfusion technique to fix the damaged RC lattice beams and shell slabs. Nevertheless, no thorough investigation has been performed to inspect the chapel's overall structural system. To fill the gap, this study aimed to examine the chapel's overall structural system and evaluate the structural damages caused by the 921 earthquake and daily use.

1. Methods

Luce Chapel is 19.65-m high. Due to its unique hyperbolic structure, it would be problematic to apply scaffolding, which is commonly used in outdoor construction. Although scaffolding can be used inside the chapel to conduct indoor inspections, this would also cause inconvenience to the chapel's regular activities (e.g., regular gatherings and Sunday worships). Therefore, different investigation methods were applied for the indoor and outdoor inspection, and these methods are as follows:

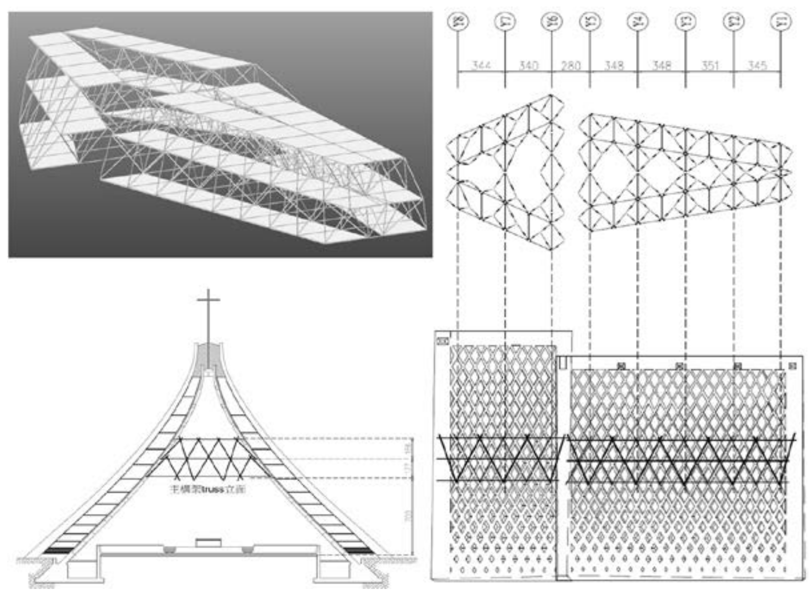
The outdoor inspection: An aerial lift truck was used to examine the outer surface damage of the shells

The indoor inspection: A temporary framework (i.e., a space truss) made of steel tubes as well as a mobile scaffold were applied to survey the damage status of the interior RC beams and slabs

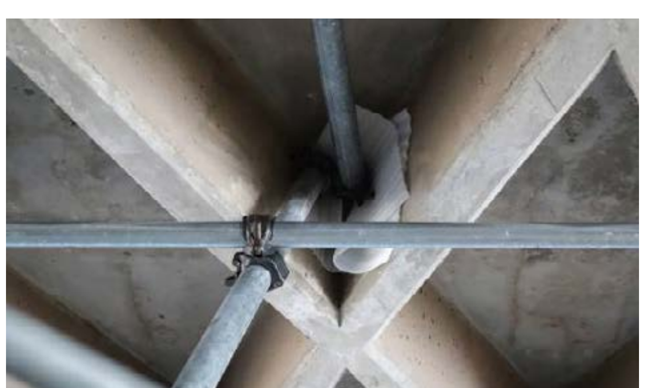
The outer surfaces of the chapel's shells were inspected inch by inch by using an aerial lift truck (Fig.4.45). The indoor inspection was conducted by using different means depending on the elevation of target areas. When the elevation was 3–7 m, a mobile scaffold (Fig.4.46) was used, whereas above the elevation of 7 m, a temporary steel-tube framework (Fig.4.47) was applied. Below the elevation of 3 m, the project research crew examined the chapel's indoor structure without using the scaffold or framework. To construct the temporary framework, steel tubes with Φ = 42.7 mm were connected using a particular type of slipknots (Fig.4.48) to form a space truss system, and special footboards were installed to facilitate the operation of the research crew.

The temporary framework in this study consisted of eight bays of trusses, which were joined using oblique bracing members to form a big space truss system (Fig. 4.49). As demonstrated in (Fig.4.50), the truss framework system was affixed to the lattice beams, through which the weight of the framework system can be transferred to the building structure. An analysis shows that this framework system can sustain live loads up to 150 kgf/cm2. The system consisted of three tiers, and the top tiers were the smallest while the bottom tiers being the smallest. Additional scaffolds were employed on the framework's top tier (Fig.4.51) to allow the research crew to examine the ceiling and rooftop windows. Furthermore, a scaffold was placed at the chapel's front entrance to provide an access to the framework.

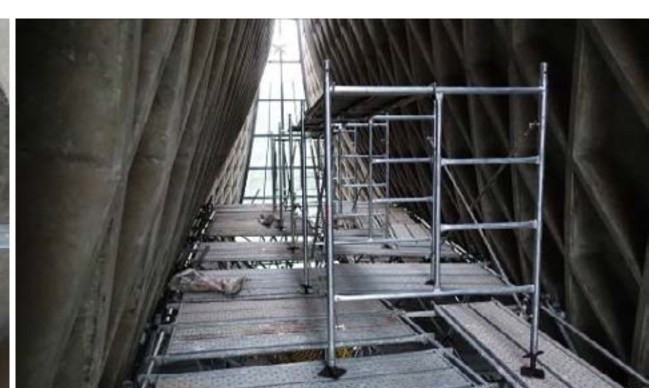
The space-truss framework system was chosen to investigate the damage located above the elevation of 7 m mainly due to three reasons: (1) the chapel's lattice-beam grids can be used to support the framework; (2) the steel-tube framework was cost-effective, light and can be quickly assembled; and (3) the framework caused no negative influence on the chapel's structure and can be easily disassembled and reused. Furthermore, the temporary framework allowed the regular chapel activities to proceed without interference.



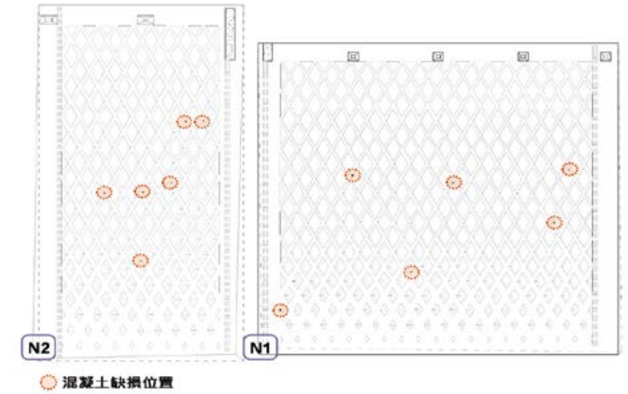
4.49 Design of the framework



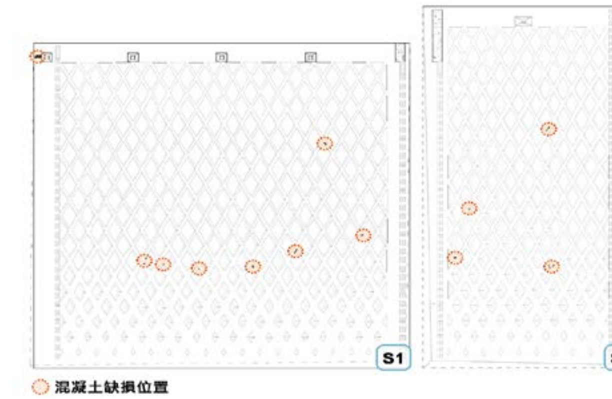
4.50 Lattice beams provided supports to the framework truss system



4.51 Additional scaffolds on the framework's top tier



4.52 Concrete deterioration spots on the lattice-beam grids and slabs on the north side of the chapel



4.53 Concrete deterioration spots on the lattice-beam grids and slabs on the south side of the chapel

4.54 Concrete deterioration caused by concrete demolding

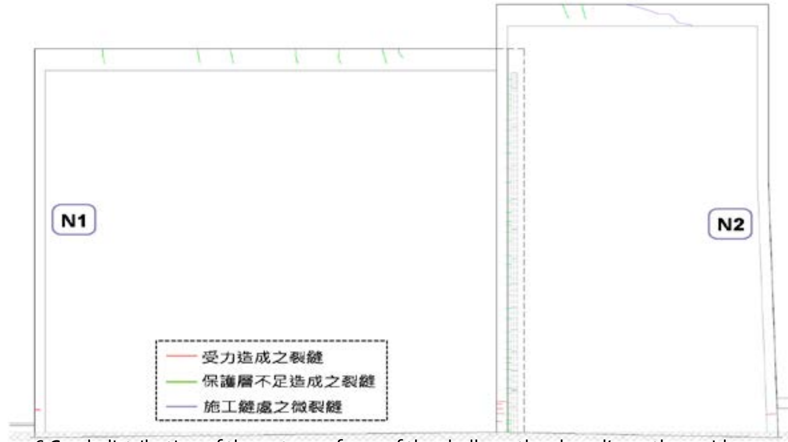
4.55 Concrete air voids formed during concrete solidification

2. Inspection Results

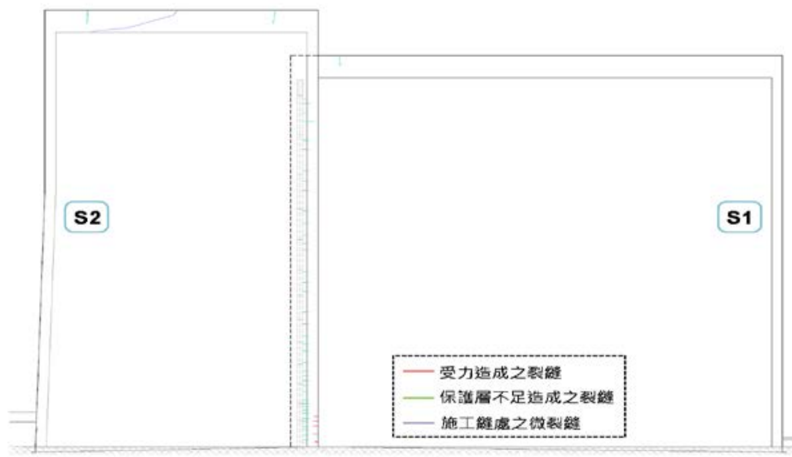
According to the damage investigation results, this study classified the damage conditions into the following types for further discussions:

Concrete Deterioration

(Fig. 3.52) and (Fig. 3.53) demonstrates concrete deterioration spots on the lattice-beam grids. This study discovered that such concrete deterioration was very minor. Most of these deteriorations occurred during the demolding process after the solidification of concrete (Fig. 3.54). Because no plastering or decoration was applied in the interior of the chapel, these concrete deterioration spots can be visually inspected. Moreover, a small portion of these concrete deterioration spots were air voids formed during concrete solidification (Fig. 3.55). In summary, the concrete deterioration of the chapel structural components was minor and unevenly distributed.



4.56 Crack distribution of the outer surfaces of the shells on the chapel's northern side



4.57 Crack distribution of the outer surfaces of the shells on the chapel's southern side

4.58 Vertical cracks at the rooftop parapet walls

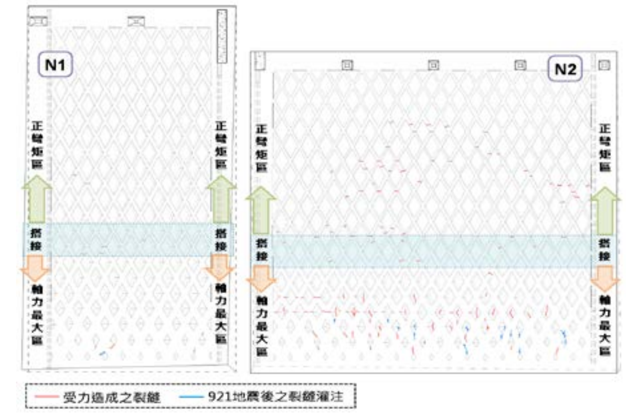
4.59 Cracks at the edge beams around the rooftop windows

4.60 Oblique cracks at the top of a shell

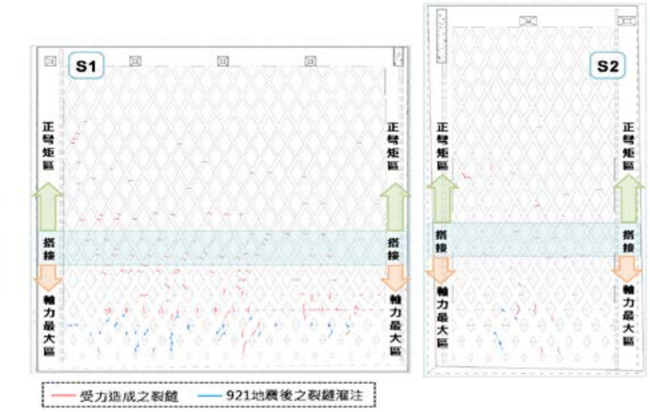
4.61 Cracks at the bottom of a shell

Cracking of the RC Beams and Slabs

(Fig.4.56) and (Fig. 4.57) display the crack distribution on the outer surfaces of the chapel's shells. As displayed, cracking primarily occurred at the shells' bottom parts, the rooftop parapet walls, and the edge beams next to the rooftop windows. Vertical cracks at the parapet walls (Fig.4.58) were caused by inadequate protection and years of outdoor exposures (sunlight, wind, and rainfall), which caused RC deterioration. Theoretically, when the reinforcing steel corrodes, the resulting rust occupies a greater volume than the steel, creating tensile stresses in the concrete and thus causes cracking. Because of this reason, cracking took place at the edge beams beside the rooftop windows (Fig.4.59) . Additionally, oblique cracks were also detected at the similar position of the two shell slabs, Slabs N2 and S2 (Fig.4.60) , which are on the chapel's northern and southern sides, respectively. These oblique cracks are the gaps of construction joints. Furthermore, insignificant horizontal cracks were observed at the bottom of the edge columns (Fig.4.61) , and these cracks occurred when the bottom parts of the edge columns were under negative bending moment, which reach a maximal value at the columns' footing.



4.62 Crack distribution of the lattice-beam grids and slabs on the chapel's northern side



4.63 Crack distribution of the lattice-beam grids and slabs on the chapel's southern side

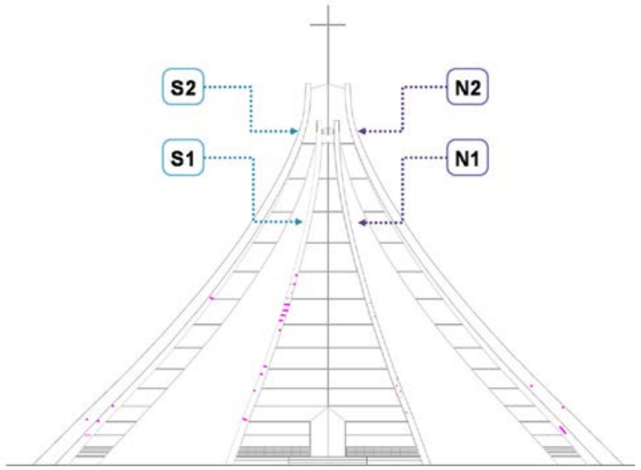
(Fig.4.62) and (Fig.4.63) indicate the crack distribution on the lattice-beam grids and slabs inside the chapel. When the overlapping areas of reinforcing bars (i.e., the light blue areas) serve the boundaries for three cracking zones. This study discovered that after the 921 earthquake, a grouting technique was applied to repair earthquake-induced cracks, which concentrated on the lower parts of the lattice-beam grids and slabs (Fig.4.64). In addition to these repaired cracks, more cracks (width = 0.3–0.6 mm) were observed at the lower parts of the lattice-beam grids and slabs (Fig.4.65), indicating that substantial tensile forces and earthquake-induced shear forces both occurred at these locations. Furthermore, cracks appear at the reinforcing bar overlapping areas of the lattice beams because the overlapping of reinforcing bars causes unfavorable reinforcing bar gripping, thus leads to the cracking of the lattice beams when under external forces (Fig.4.66). Cracks also exist at the lattice beam areas above the overlapping areas of the reinforcing bar (Fig.4.67). Since the lattice beams narrows from the bottom to the top, they are prone to crack when subjected to positive bending incurred by static vertical loads. Cracks in these areas are smaller (i.e., 0.25–0.35 mm) than cracks at the lower parts of the lattice beams.

4.64 Crack repaired after the 921 earthquake by using the grouting technique

4.65 Lattice-beam cracking at the shell footing

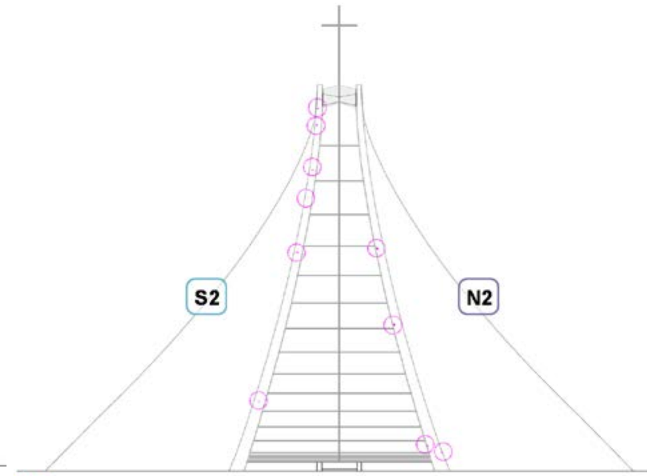
4.66 Cracking at a reinforcing bar overlapping area

4.67 Thin cracks on the upper half of a lattice beam



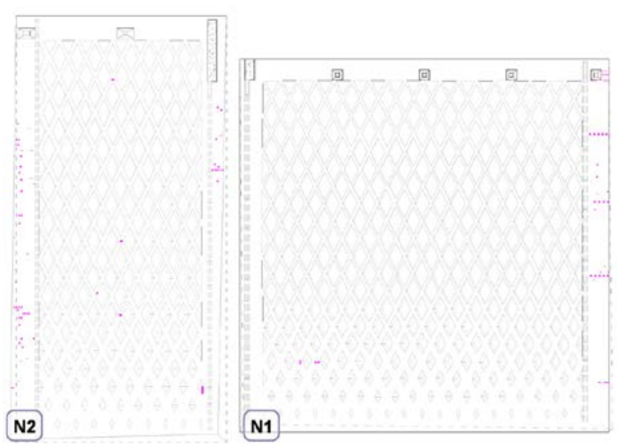
鋼筋或螺桿鏽蝕外露位置

4.68 Distribution of corroded reinforcing bars and bolts (the east elevation view)



鋼筋或螺桿鏽蝕外露位置

4.69Distribution of corroded reinforcing bars and bolts (the west elevation view)



鋼筋或螺桿鏽蝕外露位置

4.70 Distribution of corroded reinforcing bars and bolts (the north elevation view, the lattice-beam grids, and slabs)

鋼筋或螺桿鏽蝕外露位置

4.71 Distribution of corroded reinforcing bars and bolts (the south elevation view and the lattice-beam grids and slabs)

Corrosion of Reinforcing Bars or Bolts

(Fig.4.68) – (Fig.4.71)display the reinforcing steel corrosion distribution on the chapel's shell slabs. Steel corrosion primarily occurs on exposed reinforcing steel, which locates at the outer surfaces of the shells. Such corrosion was caused by insufficient concrete protection and long-term environmental influence, which led to moisture infiltration in the concrete structure, and corrosions on the reinforcing steel. The expansion of the corroded steel created tensile stresses within the concrete thus caused cracking and even concrete peeling. Moreover, with its 50 years of history, neutralization of the concrete may be another cause of corrosion on reinforcing steel.

According to the distribution of corroded reinforcing bars and bolts on the chapel's eastern and western sides (Fig.4.68) and (Fig.4.69), steel corrosion primarily occurs at the edge columns. The steel corrosions at some locations are associated with concrete spalling and horizontal reinforcing bar exposure (Fig.4.72). Steel corrosion were also identified at the bottom of the edge columns next to the side windows (Fig.4.73) and the lower parts of the lattice beams (Fig.4.70)and (Fig.4.71). Severe steel corrosion resulted concrete cracking and peripheral damage (Fig.4.74). Furthermore, the outer side of the rooftop pin joints exhibits similar steel corrosion states as well (Fig.4.75).
In contrast to the chapel's exterior RC surfaces, the steel corrosion indoor is less severe. The indoor steel corrosions primarily appear on the lattice-beam grids, forming small pits on the beam surface (Fig.4.76). Exposed screw rods, which were used to affix the formwork during the construction process, also corroded (Fig.4.77).


4.72 Corroded reinforcing bars at an edge column


4.73 Corroded reinforcing bars at a window frame


4.74 Corroded reinforcing bars at the bottom of a lattice beam


4.75 Steel corrosion at a rooftop joint


4.76 Reinforcing steel corrosion on the lattice beams

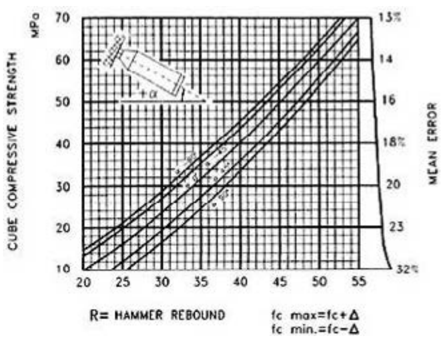

4.77 Corrosion of a screw rod inside the chapel

Nondestructive Inspection on the Structure of the Chapel

Before the assessment of chapel's structural performance, the current state of the chapel structure was examined to compare the actual construction with the original designs. Inspections on the load-carrying capacity and reinforcement arrangement of the RC components were also conducted before the assessment of structural performance. Due to the restriction on using destructive inspection methods, this study employed a rebound hammer test and a ground-penetrating radar (GPR) system to conduct a nondestructive inspection.

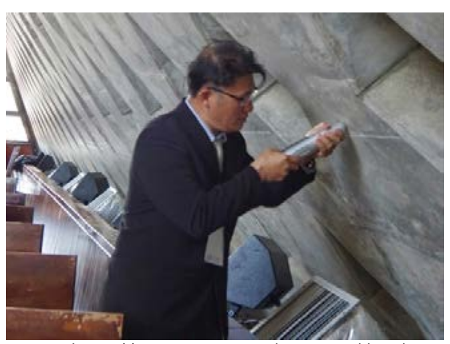
1. Rebound Hammer Test

In this study, rebound hammer tests were employed to determine the compressive strength of the concrete structure, and the test results were then used for further analyses. In the rebound hammer test, a spring-controlled mass was first pressed against the surface of the concrete following the rebound of the hammer; the extent of the rebound determined its rebound number, which was used to estimate the compressive strength of the concrete. The concrete compressive strength was converted in accordance with the given rebound numbers presented in (Fig.4.78). In order to obtain the precise rebound values, the hammer must remain perpendicular to the tested surface (Fig.4.79). In this study, proceq N-34 rebound hammers were applied on selected smooth surfaces of the lattice-beam grids and slabs. Rebound hammer tests were conducted both on and above ground level (Fig.4.80). The research crew used a temporary framework as the testing points elevated (Fig.4.81) (Fig.4.82) and (Fig.4.83) summarizes the results of the rebound hammer tests.

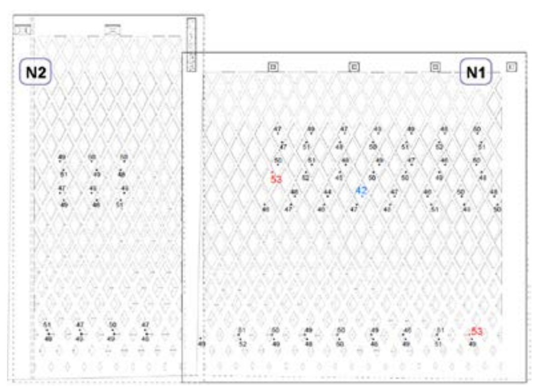


4.78 Curves in relation between rebound numbers and cube compressive strength(15-cm test cube)

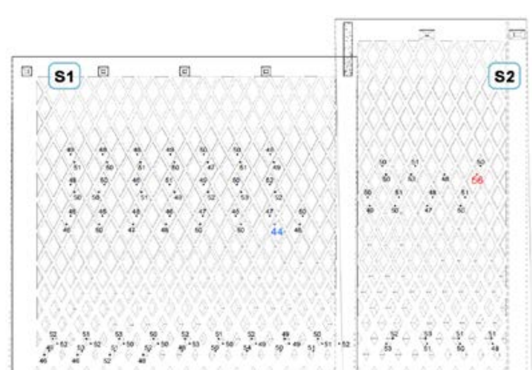

4.79 Rebound hammer test (the instrument was held perpendicular to the test surface)


4.80 Rebound hammer test at the ground level


4.81 Rebound hammer test at off-ground level accessed through a temporary framework



4.82 Rebound hammer test spots and rebound numbers on the lattice-beam grids and slabs on the chapel's northern side



4.83 Rebound hammer test spots and rebound numbers on the lattice-beam grids and slabs on the chapel's southern side

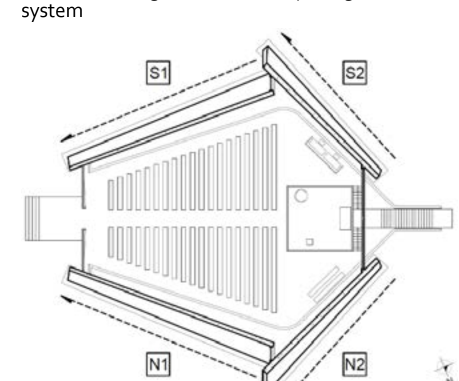
The test results were summarized in Table 4-3. The relationship between rebound numbers and concrete compressive strength was established using 15-cm concrete cubic samples rather than the typical 15×30 cm cylinder samples used for concrete compressive strength tests in Taiwan. According to proceq N-34 rebound hammer's user manual, in which the compressive strength of both sample types was listed, the ratio between the compressive strength of 15×30 cm cylinder samples and 15-cm concrete cubic samples is 0.8/1. When converting to the cylinder sample calculation, the average concrete compressive strength of Slabs S1, S2, N1, and N2 would be 430.9, 448.1, 419.9, and 415.5 kgf/cm2, respectively. This result suggests a concrete compressive strength 4000 psi higher than the original designed on each slab.

Table 4-3 Results of the rebound hammer tests

Slab	Test location	Compressive strength based on 15-cm cube samples (kgf/cm2)	Compressive strength based on 15×30 cm cylinder samples (kgf/cm2)
S1	Upper part	519.82	415.86
	Lower part	557.34	445.87
	Average	538.58	430.86
S2	Upper part	549.29	439.43
	Lower part	571.04	456.83
	Average	560.16	448.13
N1	Upper part	513.42	410.73
	Lower part	536.25	429.00
	Average	524.83	419.87
N2	Upper part	525.15	420.12
	Lower part	513.68	410.95
	Average	519.42	415.53


4.84 GPR devices


4.85 Reinforcing bar detection by using a GPR system



4.86 Schematic diagram of the detection direction

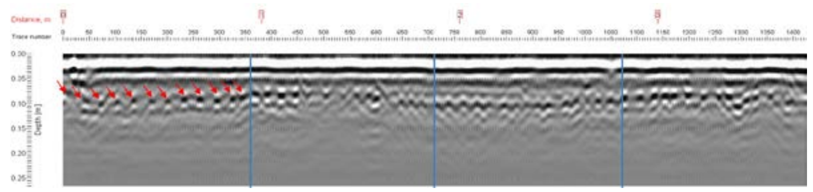
2. Reinforcing Bar Detection

To determine whether Luce Chapel was constructed according to its original design, this project committee entrusted C. C. Cheng, a professor of the Department of Construction Engineering at Chaoyang University of Technology, to locate reinforcing bars by using a GPR system. The original drawings and diagrams of the chapel are very well preserved and were used for the assessment of this inspection.

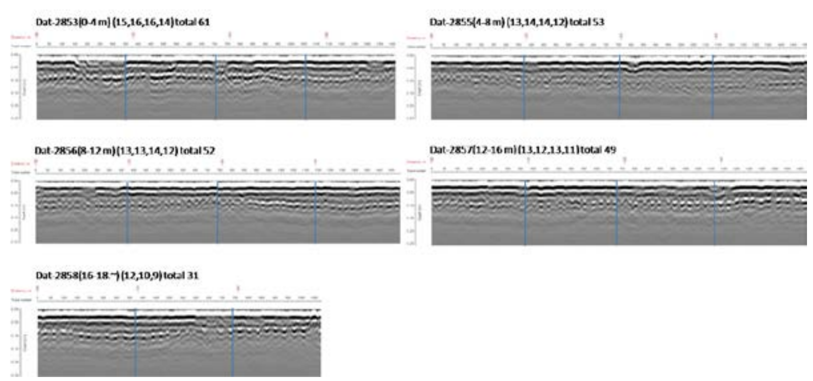
The GPR system uses electromagnetic radiation to detect energy changes of reflected radar pulses from subsurface structures. Consequently, layers of structure beneath the surface can also be identified. In other words, a GPR transmitter continuously emits electromagnetic radio signals to a target surface, and a fixed or mobile receiving antenna is then used to record the signals that are reflected by a buried object and to send the signals to a data processor, which analyzes the object's mechanical properties. A GPR system consists of transmitting and receiving antennas in addition to a signal recording and analyzing system, of which the monitor can display the reflected electromagnetic waves, demonstrating subsurface structures.

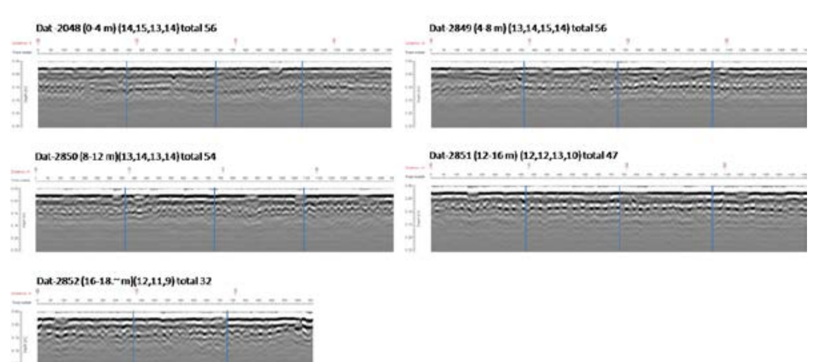
This study focuses on detecting the reinforcement arrangement of the shell slabs. In the detecting process, the GPR system was used to examine the shells' outer surfaces at a height of 1.2 m from the chapel's west end to east end. To facilitate data processing, the detection length was 4 m; namely data were recorded after the examination of every 4-m of the test surface (Fig.4.86).

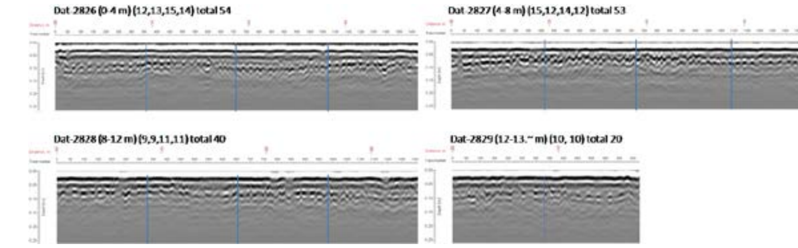
The data of Slab S2 at a distance range of 0–4 m (Fig.4.87) is used here to exemplify how the GPR detected data was interpreted:
Dat-2826: Data file name
(0–4 m): Slab S2 was detected in a distance range of 0–4 m (measured from the slab's furthest end) and at a height of 1.2 m
(12, 13, 15, and 14): The reinforcing bar numbers in the distance ranges of 0–1 m, 1–2 m, 2–3 m, and 3–4 m, respectively.
Total 54:A total of 54 reinforcing bars exist in the wall in the distance range of 0–4 m
Dat-2826 (0–4 m) (12, 13, 15, and 14) total 54

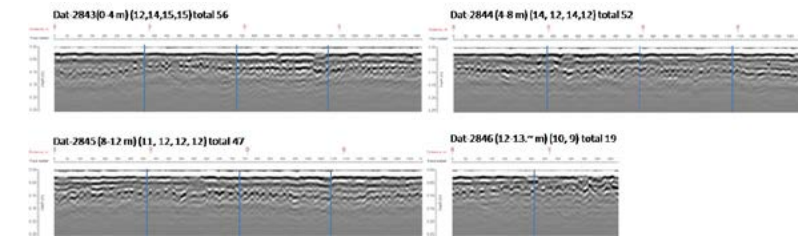

4.87 Reinforcing bar detection image of Slab S2 (0–4 m)

As displayed in (Fig. 3.87), the detection length is 4 m, and the vertical and horizontal axes represent the detection depth from the test surface and the detection distance from Slab S2's foremost boundary, respectively. However, because the test surfaces were not smooth, and the speed of the GPR's roller was not constant, errors existed in the distance calculation (the number of detection segments × 4 m). In this situation, the distance was re-calculated, and the blue lines in (Fig. 4.10)re marked using meters as the unit. The red arrows in the image locate 12 spots of a reinforcing bar, which are all in the depth of 0–0.1 m, thereby indicating the depth of the reinforcing bar to be 0.1 m. Reinforcing bar detection images of Slabs S1, N1, S2, and N2 are presented in (Fig. 3.88)–(Fig. 3.91), respectively.

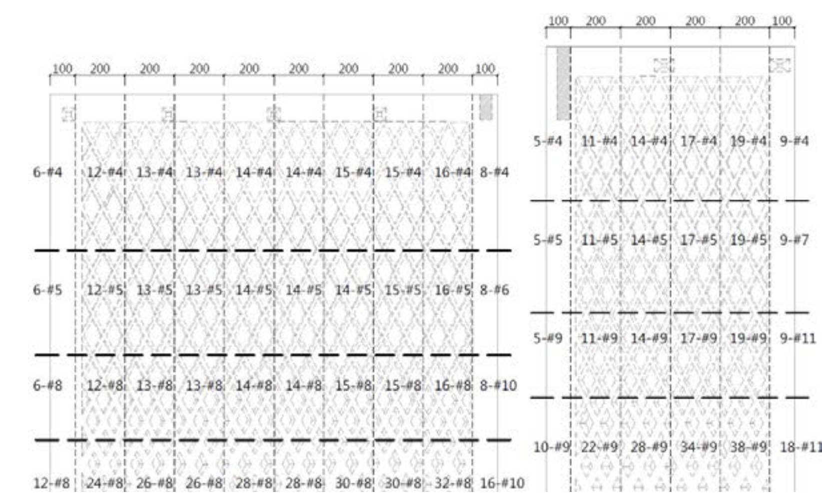

4.88 Reinforcing bar detection image of Slab S1


4.89 Reinforcing bar detection image of Slab N1


4.90 Reinforcing bar detection image of Slab S2


4.91 Reinforcing bar detection image of Slab N2

This study regenerated vertical reinforcement diagrams (Fig.4.92) on the basis of the original reinforcement drawings. Because the original diagrams were drawn in a projected view, the detected reinforcement diagrams were converted into a projected view accordingly to facilitate the reinforcement comparison. The analyzed results are summarized in Table 4-4 and Table 4-5.



4.92Vertical reinforcement arrangement of the shell slabs (digitally regenerated structural diagrams, CHS5 and CHS6)

Table 4-4 Comparison between the detected reinforcement arrangement and original reinforcement designs of Slabs S1 and N1

Location (m)	0-1(frame)	1-3	3-5	5-7	7-9	9-11	11-13	13-15	13-15	17-18(frame)	total
Designed reinforcing bar number	16	32	30	30	28	26	24	24	24	12	246
S1	16	33	29	29	27	28	27	26	26	10	246
N1	15	31	29	30	29	29	26	25	25	10	245

Table 4-5 Comparison between the detected reinforcement arrangement and original reinforcement designs of Slabs S2 and N2

Location (m)	0-1(frame)	1-3	3-5	5-7	7-9	9-10 (frame)	total
Designed reinforcing bar number	18	38	34	28	22	10	150
S2	17	38	37	29	29	17	167
N2	18	39	36	32	32	17	174

Results

Table 3-4 reveals that the detected reinforcement arrangement is consistent with the original design. The reinforcement arrangement of Slabs S1 and N1 exhibited a similar pattern, in which the reinforcement amount gradually decreases from the chapel's east to its west. The total numbers of the reinforcing bars of Slabs S1 and N1 are 246 and 245, respectively, and these numbers are consistent with the number in the original design (246).

Slightly different from the original design, the detected reinforcement in Slabs S2 and N2 decreases gradually from the chapel's west end to its east end (Table 4-5). However, two edge columns at the locations of 0–1 m and 9–10 m with the identical amount of reinforcing bars are different from the original reinforcement design, in which the west edge column was to have 18 reinforcing bars, whereas the east edge column should have had 10 reinforcing bars. Moreover, the reinforcement amount in the distance ranges of 5–7 m and 7–9 m is also constant instead of decreasing. The total numbers of the reinforcing bars in Slabs S2 and N2 are 167 and 174, respectively, whereas those of the original design were 150, indicating the application of additional vertical reinforcing bars during the construction.

Seismic Analysis

When a structure is subjected to a dynamic load (i.e., wind or earthquake load), the load will induce time-dependent displacements and deformations as well as vibration responses in the structure. The extent of such responses is associated not only with the magnitude and frequency of the dynamic load but also with the structure's natural frequency or vibration modes. Given a structural system differs from the regular RC beam-column systems, a new simulation model for dynamic behavior examinations had to be developed in order to determine the chapel's dynamic properties.

1. Model Development and Assumptions

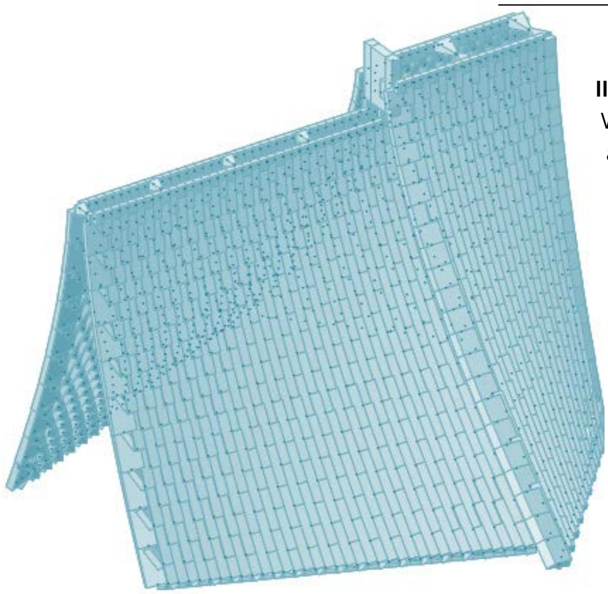
This study employed a structural analysis software, MIDAS/Gen V7.9.5 (2012 V1.1), to perform a dynamic analysis on Luce Chapel's structure in an attempt to identify the structure's vibration modes and natural frequency. When the model was developed, a frame element and a shell element were used to simulate the non-uniform lattice beams and slabs, respectively. The model assumptions are described as follows:

I. Materials

The results of the rebound hammer tests in Section 4.1 reveal the average concrete compressive strength, which was higher than the original design value by 4000 psi. Conservatively, a concrete compressive strength of fc ´ = 280 kgf /cm2 was applied on the simulation model to correspond with the original design. The model's material parameters are as presented in Table 4-6.

Table 4-6 RC mechanical properties

Material	Compressive strength fc´	Density	Modulus of elasticity Ec	Poison ratio υ	Thermal expansion coefficient α
RC	280 kgf/cm2	2400 kgf/m3	21 GPa	0.167	9.9x10-6 /ºC



4.93 Structural model of Luce Chapel

II. Boundary conditins

While modeling the boundary conditions, relevant RC components were assumed to be pin-connected with the corresponding foundations, following a structure without an underlying ground. In the model, the X axis aligned in the east-west direction, Y axis in the south–north direction, and the Z axis in the vertical direction. To achieve a favorable simulation result, the members and joints of the model were developed according to their actual sizes and configurations, and the bending moments of the beams were set to be zero along the ridgeline. Notably, the model development focused on the chapel's major structural components, and non-structural members, such as rooftop windows and window frames between the slabs weren't part of the simulation. The developed model is demonstrated in (Fig.4.93).

Table 4-7 Dominant vibration modes and the corresponding periods

Vibration modes	Period	TRAN-X		TRAN-Y		TRAN-Z		ROTN-X		ROTN-Y		ROTN-Z	
	(sec)	Mass (%)	Sum (%)	Mass (%)	Sum (%)	Mass (%)	Sum (%)	Mass (%)	Sum (%)	Mass (%)	Sum (%)	Mass (%)	Sum (%)
1	0.388	1.48	1.48	0.00	0.00	2.68	2.68	0.00	0.00	0.82	0.82	0.00	0.00
2	0.366	0.00	1.48	6.90	6.90	0.00	2.68	1.65	1.65	0.00	0.82	8.90	8.90
3	0.332	0.00	1.48	2.09	8.98	0.00	2.68	8.18	9.83	0.00	0.82	3.98	12.89
4	0.283	9.27	10.75	0.00	8.98	0.13	2.81	0.00	9.83	0.91	1.73	0.00	12.89
5	0.266	0.00	10.75	0.46	9.44	0.00	2.81	8.46	18.29	0.00	1.73	0.00	12.89
6	0.255	2.25	13.00	0.00	9.44	3.70	6.50	0.00	18.29	1.03	2.76	0.00	12.89
8	0.219	10.38	23.38	0.00	13.40	0.48	6.98	0.00	19.15	0.28	3.04	0.00	13.21
9	0.210	0.00	23.38	0.95	14.34	0.00	6.98	2.04	21.19	0.00	3.04	0.02	13.23
10	0.206	0.83	24.21	0.00	14.34	5.19	12.17	0.00	21.19	0.15	3.19	0.00	13.23
16	0.154	0.00	24.26	7.46	25.23	0.00	13.22	0.03	24.41	0.00	4.90	0.30	15.24
18	0.143	0.00	24.26	6.54	31.78	0.00	13.31	0.12	24.53	0.00	5.78	0.82	16.07
28	0.113	3.23	29.06	0.00	35.89	0.21	15.52	0.00	26.48	0.01	7.78	0.00	19.88
44	0.084	1.72	35.87	0.00	37.80	1.24	17.70	0.00	32.70	13.45	27.06	0.00	21.55
50	0.077	2.61	41.30	0.00	38.98	0.00	17.70	0.00	33.30	3.14	32.26	0.00	21.76
53	0.073	2.63	44.87	0.00	39.01	0.02	18.18	0.00	33.76	2.69	35.98	0.00	21.89
164	0.033	0.00	60.47	0.52	53.35	0.00	26.16	1.11	45.42	0.00	46.47	3.18	39.89
200	0.028	0.00	65.02	0.12	56.70	0.00	27.70	0.13	47.79	0.00	47.81	0.54	44.33

2. Results

After the model was created, a modal analysis was conducted by examining the structure's first 200 natural vibration modes and the participating mass ratios of these modes. Table 4-7 summarizes the analytical results related to selected vibration modes. The cumulative sums of the 200 models participating mass ratios in the X, Y, and Z axes are listed as follows:

1. X axis (the east–west direction) 65.0%
2. Y axis (the south–north direction) 56.7%
3. Z axis (the vertical direction) 27.7%

The cumulative model participating mass ratios in the X and Y axes both exceeded 50%, indicating the sufficiency of the 200 vibration modes in representing the structure's major horizontal vibration responses.

The dominant vibration modes in each direction can be obtained by identifying vibration modes that have the maximal participating mass ratios in the 200 vibration modes. As a result, the dominant vibration modes are the 4th and 8th modes for the X axis, the 2nd and 16th modes for the Y axis, and the 10th mode for the Z axis. Notably, the 2nd mode indicated considerable torsional vibrations.

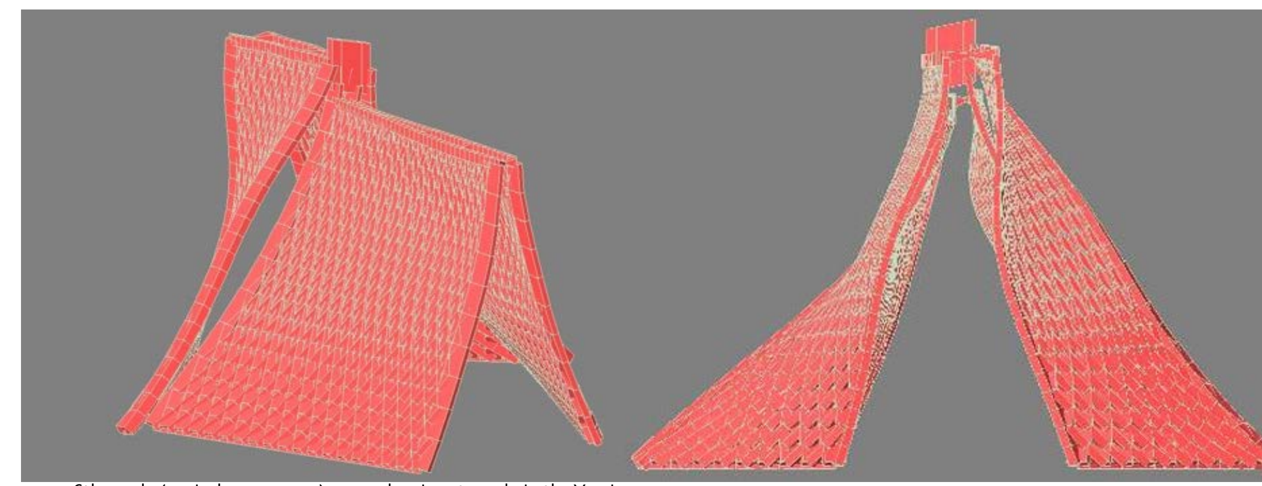
3. Dominant Vibration Modes and Corresponding Periods

As presented in Table 3 7, the vibration period and participating mass ratio of the 16th mode are 0.154 sec and 7.46% respectively. The 16th mode thus dominates the responses in the Y axis, namely the shells' off-plane deformation (Fig.4.94). Moreover, the vibration period and participating mass ratio of the 2nd mode are 0.366 sec and 6.90% respectively, and the participating mass ratio of the 2nd mode in the Z axis is 8.90%, indicating this mode induces torsional vibration in addition to lateral vibration (Fig.4.95). In the Y axis, the 2nd and 16th modes have substantial participating mass ratios, of which the values are close, making the two modes the dominant vibration modes in the Y axis.

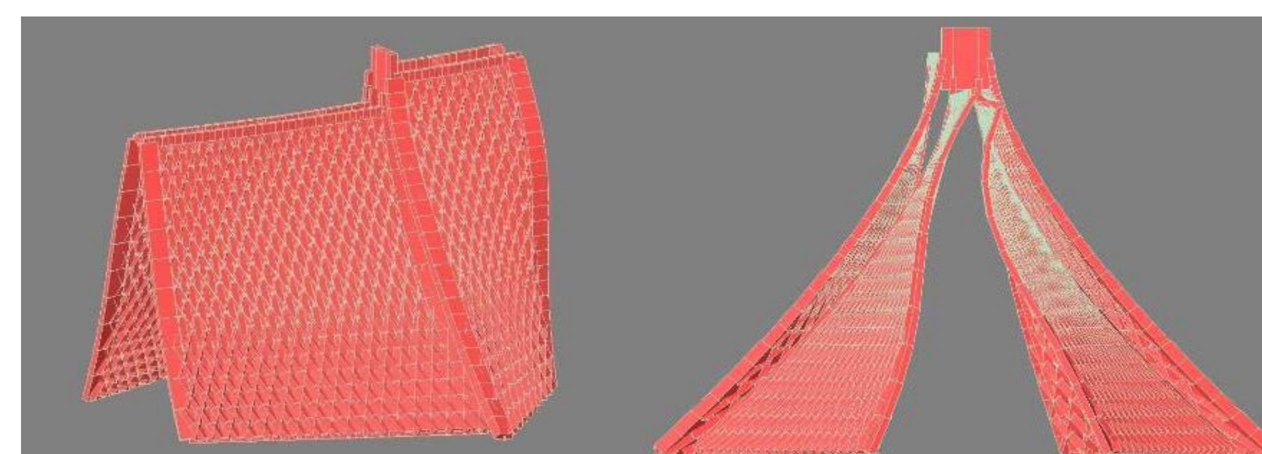
Furthermore, the 4th mode has the period of 0.283 sec and participating mass ratio of 9.27% (Fig.4.96), and the 8th mode has the period of 0.219 sec and participating mass ratio of 10.38% (Fig.4.97). The two modes are the dominant modes in the X axis, inducing the shells' in-plane deformations along the east–west direction.

The 10th mode has the period of 0.206 sec and is the dominant mode in the Z axis, whereas the other modes induce minor seismic responses.

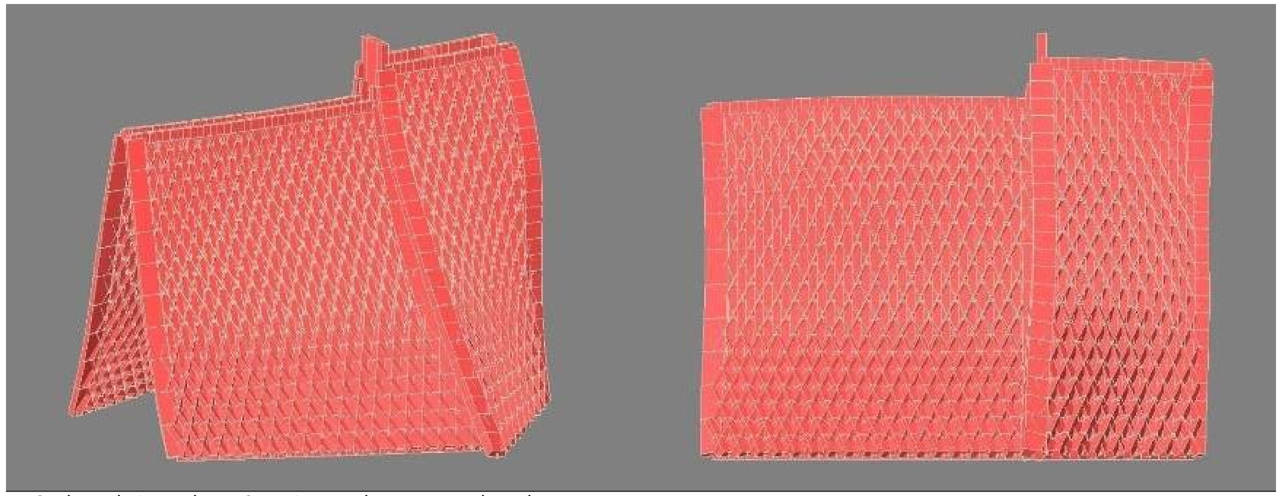
In summary, the dynamic analysis indicates the Luce Chapel to be a short-period structure, and the chapel's original structural design was rather conservative in terms of seismic design.



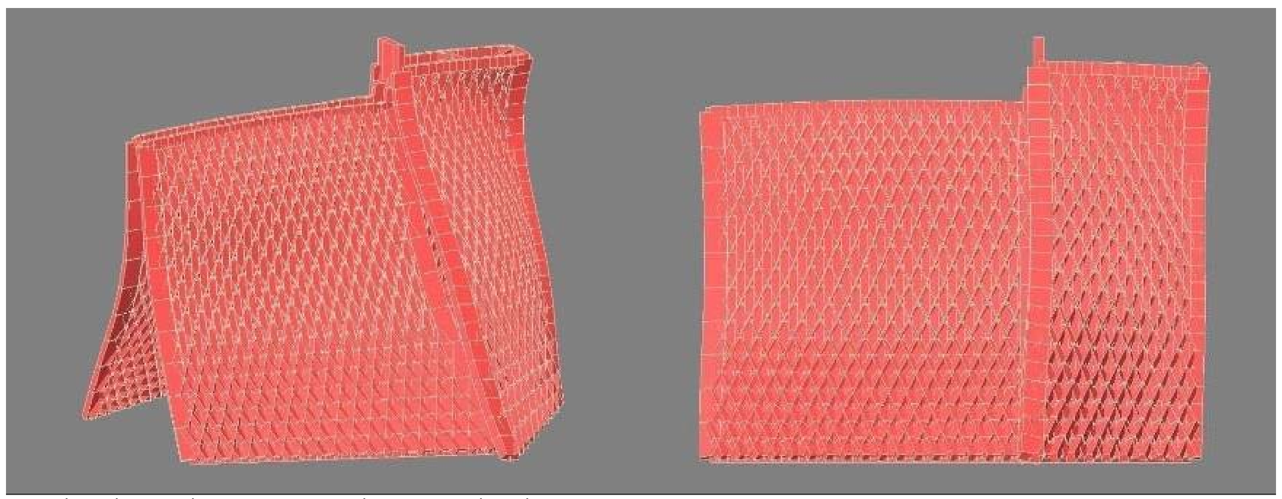
4.94 16th mode (period = 0.154 sec) was a dominant mode in the Y axis



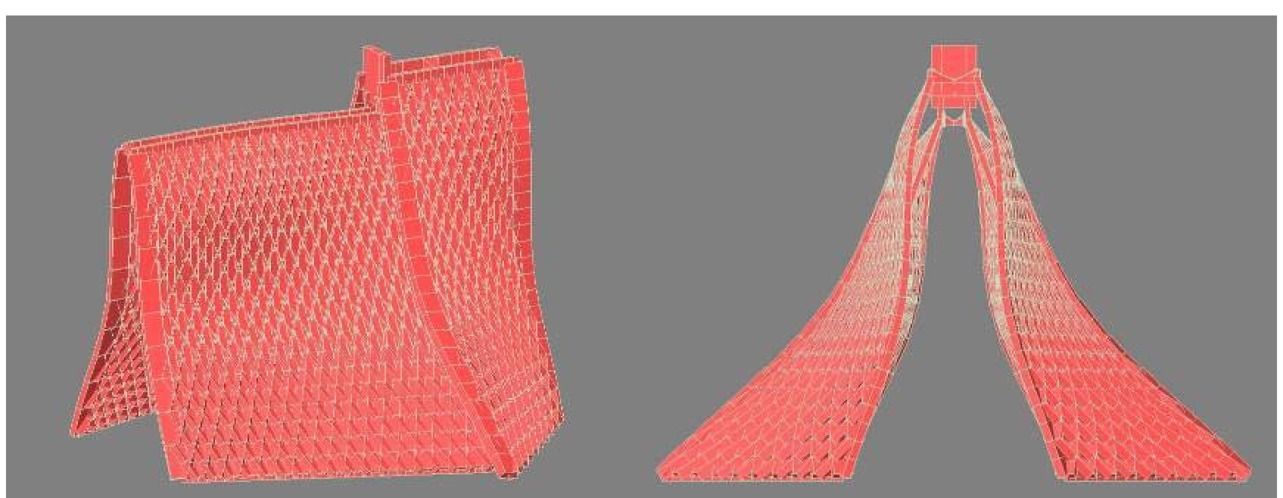
4.95 2nd mode (period = 0.372 sec) was a dominant mode in the Y axis and induced substantial torsional vibration



4.96 4th mode (period = 0.283 sec) was a dominant mode in the X axis



4.97 8th mode (period = 0.219 sec) was a dominant mode in the X axis



4.98 10th mode (period = 0.206 sec) was a dominant mode in the Z axis

Structural Safety Assessment

The island of Taiwan resides at the boundary between the Philippine Sea Plate and Eurasian Plate and is on the circum-Pacific seismic belt, which is one of the most seismically active regions in the world. Therefore, the assessment of structural safety must consider the structure's performance under seismic loading along with long-term loading. This study applied Taiwan's regulations regarding building seismic designs to evaluate the seismic performance of Luce Chapel and specifically calculated the forces carried by each structural component. In the end, the effectiveness of the chapel's original reinforcement designs was assessed to determine the safety of the chapel structure.

1. Load Types and Combinations

Dead and Live Loads

The chapel's dead loads were determined using structural software MIDAS/Gen V7.9.5 (2012 V1.1). According to regulations pertaining to special building types and usage statuses, no live loads were evaluated in the subsequent seismic analysis.

Seismic Loads

The chapel structure's seismic loads were calculated with reference to Building Technical Regulations and Seismic Design Specifications and Commentary of Buildings (SDSCB), published by the Construction and Planning Agency under the Ministry of the Interior of Taiwan. To perform a static analysis, the minimal horizontal seismic design force V was calculated by

$$V = \frac{S_{aD} \cdot I}{1.4 \cdot \alpha_y F_u} \cdot W$$

(Equation 2-1 in SDSCB)

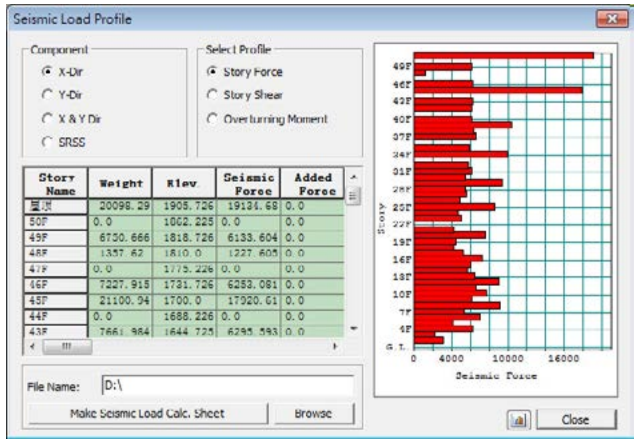
where SaD: The ground horizontal acceleration response spectral coefficient of the building site.
I: Building factor; because Luce Chapel is a public building for the purpose of cultural education, it is thus categorized in building Type III with I = 1.25.
W: The sum of the chapel's dead loads.
αy: Seismic force amplification factor, and αy = 1.0 for RC structures.
Fu: Seismic force reduction factor.

According to the determined spectral coefficients of the horizontal acceleration response for the chapel site, the chapel's basic vibration period was identified from a dynamic analysis, and seismic force factors were considered in the ductility design concept. The chapel's seismic forces were determined as follows:

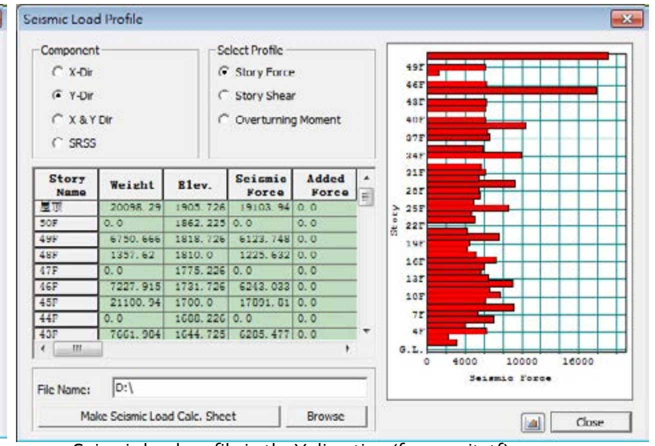
$$V_x = \max\left(V_{D,X}, V_{M,X}, V_X^*\right) = \max\left(0.309W, 0.204W, 0.308W\right) = 0.309W$$

$$V_y = \max\left(V_{D,Y}, V_{M,Y}, V_Y^*\right) = \max\left(0.307W, 0.109W, 0.308W\right) = 0.308W$$

Subsequently, these seismic forces were input in the chapel's structural model, and the model calculation generated the following seismic load profiles:



4.99 Seismic load profile in the X direction (force unit: tf)



4.100 Seismic load profile in the Y direction (force unit: tf)

Load Combinations

By referencing the Code for Design of Concrete Structures (CDCS), this study employed the following load combinations:

(1) U = 1.4D
(2) U = 1.2D ± 1.0E
(3) U = 0.9D ± 1.0E

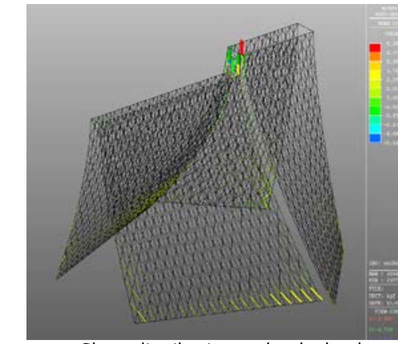
Where D: Dead load, including the weight of structural components and attachments that are permanently affixed to the building.
E: Seismic load, which is determined according to SDSCB.

1. Shear Capacity Check

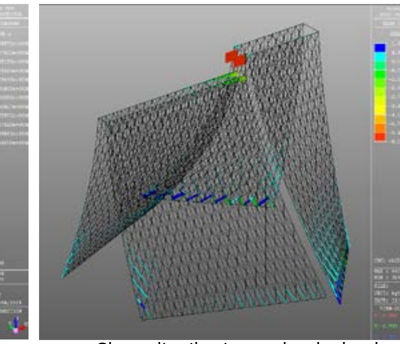
The shear capacity check focused on the maximum shear capacity of the lattice-beam grids and other maximal shear stress locations, which were identified in the aforementioned structural analysis of the chapel. According to the CDCS, this study evaluates the shear-carrying capacity of the components through the following equations:

$\phi Vn \geq Vu$ (Equation 4-1 in CDCS)
$Vn = Vc + Vs$ (Equation 4-2 in CDCS)
Where Vn: Shear strength of the component (kgf)
Vu: Shear design force (kgf)
Vc: Shear strength of the concrete (kgf)
Vs: Shear strength of the reinforcing bars (kgf)
ϕ: Strength reduction factor, ϕ = 0.75 for shear strength

The shear distribution under U = 1.2D + 1.0Ex revealed that the maximal shear force (i.e., Vmax = 82.69 tf) occur at the front–back shell conjunction (Fig.4.101). When the chapel structure was loaded under U = 1.2D – 1.0Ex, the maximum shear force was Vmax = 13.05 tf at the bottom of the lattice-beam grids (Fig.4.102). In the chapel's original design, the concrete design strength was 4000 psi (i.e., fc´ = 280 kgf /cm2), and the steel yield strength fy of the reinforcing bars was 2800 kgf /cm2. The results of the shear capacity check in Table 4-8 indicated that the shear design forces Vu of the deep beam at the front–back shell conjunction and the lattice beams were lower than the corresponding shear strength ϕVn. This shows that the original cross-sectional and reinforcement designs meet the shear requirement prescribed in the CDCS.



4.101 Shear distribution under the load combination 1.2D + 1.0Ex (unit: kgf)



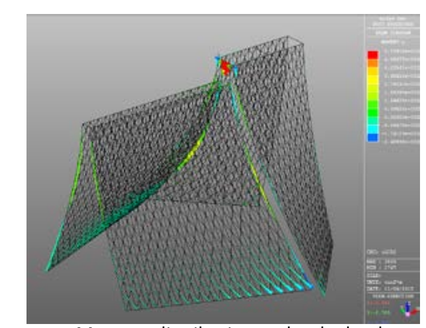
4.102 Shear distribution under the load combination 1.2D – 1.0Ex (force unit: kgf)

Table 4-8 Luce Chapel structure's shear capacity check

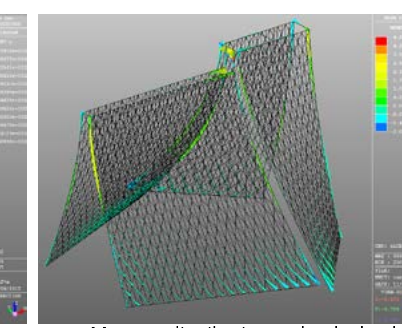
Location	Load combination	Maximal shear force Vu (tf)	Cross-sectional area (cm2)	Shear strength of the concrete Vc (tf)	Shear strength of the reinforcing bar Vs (tf)	Shear strength ϕVn (tf)	Acceptance
Deep beam at the front–back shell conjunction	1.2D + 1.0Ex	82.69	50 × 270	119.73	278.58	298.73	Yes
The bottom part of the lattice-beam grids	1.2D – 1.0Ex	13.05	94.8 × 35.9	25.22	7.95	24.88	Yes

3. Bending Capacity Check

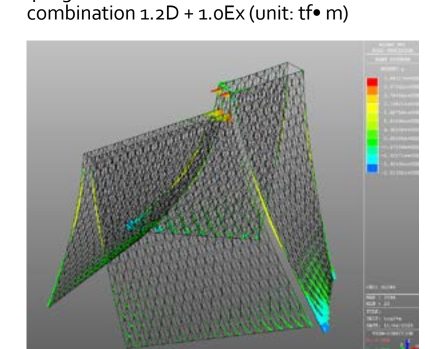
The maximal bending moment of each structural component was determined in the aforementioned structural analysis, and the results were used to check whether the original reinforcement design of the component ensures its adequate bending capacity. According to the structural analysis, the load combinations 1.2D + 1.0Ex, 1.2D + 1.0Ey, 1.2D – 1.0Ex, and 0.9D + 1.0Ey can yield substantial bending moments (Fig.4.103) – (Fig.4.106).



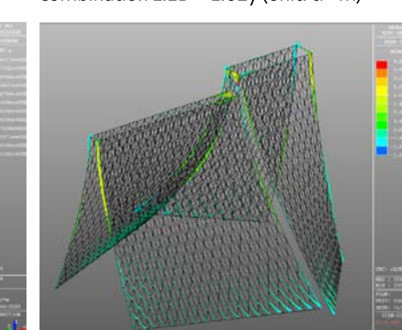
4.103 Moment distribution under the load combination 1.2D + 1.0Ex (unit: tf• m)



4.104 Moment distribution under the load combination 1.2D + 1.0Ey (unit: tf• m)



4.105 Moment distribution under the load combination 1.2D – 1.0Ex (unit: tf• m)



4.106 Moment distribution under the load combination 0.9D + 1.0Ey (unit: tf• m)

Table 4-9 Bending capacity check of Component 6

鋼筋混凝土梁彎矩檢核										
外力條件	Mu=	12.0	tf-m	=	1,201,000	kgf-cm				
	Vu=	0.0	tf							
	Tu=	0.0	tf-m							
	Pu=	0.0	tf							
構件基本資料	fc'=	**280**	kgf/cm²							
	梁寬=	**115**	cm							
	梁深=	**25**	cm							
	主筋直徑=	**D25**	25.4	mm=	2.5	cm	5.067	cm²	**4200**	kgf/cm²
	箍筋直徑=	**D10**	9.53	mm=	1	cm	0.7133	cm²	**2800**	kgf/cm²
	保護層=	**2**	cm	b=	115	cm	β1=	0.85		
	上層筋			d=	17.5	cm				
設計	Rn=Mu/(phi*bd^2)		37.890	bd2=	35,219	cm3				
	ρb=	**0.0286**								
	ρ=	0.009883	0.85fc'/fy*(1-(1-2*Rn/0.85/fc')^0.5)				**OK**			
	ρmin=	0.00333	< ρ	ρ=	0.00988					
	ρmax=	0.0215	> ρ	ρ=	0.00988					
				As,req	19.89	cm²				
檢核	忽略壓力筋作用，僅考慮下層筋									
	支數=	4	-D25	ρ=	0.01007			理論支數	**4**	
	As=	20.268	cm2	a=	3.110	cm		理論支數<=2時，以2計		
				c=	3.66	cm				
				Mn=	1,357,320	kgf-cm				
				=	13.57	tf-m				
				φMn=	12.22	tf-m	**>=Mu**			

Table 4-10 summarizes the results of the bending capacity check of the RC components. The results revealed that the cross-sectional and reinforcement designs of the RC components conform to the current design regulations. For example, regarding a component (coded as Component 6) that is located at the upper part of the edge column and adjacent to the outer surface of Shell N1, the cross-sectional area of the component was 115 × 25 cm with 6#8 D25 reinforcing bars arranged at the cross section's bottom. Component 6 had the maximal bending moment (Mx = 12.01 tf •m) when the chapel structure was subjected to U = 1.2D + 1.0Ey, and such maximal bending moment requires 4#8 D25 reinforcing bars. The detailed calculation is demonstrated in Table 4-9.

Moreover, the lattice beams located at the lower parts of Shells N1 and N2 were coded as Components 10–19 and 28–33, respectively. These beams bear negative bending moments, thus the reinforcement on their outer sides must be checked. The check results confirm the cross-sectional sizes and reinforcement designs of these beams to be current design regulations.

Table 4-10 Bending capacity check of the structural components

Component	Location		Load combination	Maximal moment Mu (tf• m)	Cross-sectional area (cm2)	Theoretical reinforcement design	Original reinforcement design	Acceptance
1	Deep beam at the front-back shell conjunction		1.2D + 1.0Ex	56.86	50 × 270	16-#6	16-#6 (reinforcing bars arranged below the cross section's neutral axis)	Yes
2	Shell N1	Edge beam along the ridgeline	1.2D – 1.0Ex	-4.69	25 × 60	2-#9	3-#9	Yes
3		Pin-joint-to-shell boundary	0.9D – 1.0Ey	9.05	50 × 50	2-#9	2-#9	Yes
4		Upper part of the edge column adjacent to the fixed connection	0.9D + 1.0Ey	2.78	115 × 25	2-#8	8-#8	Yes
5		Middle part of the edge column adjacent to the fixed connection	1.2D + 1.0Ex	15.48	115 × 40	3-#9	16-#9	Yes
6		Upper part of the edge column adjacent to the shell outer surface	1.2D + 1.0Ey	12.01	115 × 25	4-#8	6-#8	Yes
7		Middle part of the edge column adjacent to the shell outer surface	1.2D + 1.0Ey	14.58	115 × 30	4-#8	12-#8	Ye
8		Lower part of the lattice beam adjacent to rigidly connected edge columns	1.2D + 1.0Ex	2.32	38.3 × 44.5	1-#8	1-#8	Yes
9		Lower part of the lattice beam adjacent to the outer surface of the edge column	1.2D – 1.0Ex	2.13	66.5 × 34.7	1-#8	1-#8	Yes
10		Lower part of the edge column (elevation: 0–1 m)	1.2D + 1.0Ex	-24.89	115 × 55	3-#10	16-#10 (the shell slab's reinforcement design)	Yes
11		Lattice beams at the low part of the shell (elevation: 1–3 m)	1.2D + 1.0Ex	-19.21	94.8 × 50.1	3-#8	14-#8 (the shell slab's reinforcement design)	Yes
12		Lattice beams at the low part of the shell (elevation: 3–5 m)	1.2D + 1.0Ex	-18.11	94.8 × 48	3-#8	13-#8 (the shell slab's reinforcement design)	Yes
13		Lattice beams at the low part of the shell (elevation: 5–7 m)	1.2D + 1.0Ex	-10.38	94.8 × 46	3-#8	13-#8 (the shell slab's reinforcement design)	Yes
14		Lattice beams at the low part of the shell (elevation: 7–9 m)	1.2D + 1.0Ex	-9.25	94.8 × 43.9	3-#8	13-#8 (the shell slab's reinforcement design)	Yes
15		Lattice beams at the low part of the shell (elevation: 9–11 m)	1.2D + 1.0Ex	-6.54	94.8 × 42.1	3-#8	12-#8 (the shell slab's reinforcement design)	Yes
16		Lattice beams at the low part of the shell (elevation: 11–13 m)	1.2D + 1.0Ex	-5.94	94.8 × 40	3-#8	11-#8 (the shell slab's reinforcement design)	Yes
17		Lattice beams at the low part of te shell (elevation: 13–15 m)	1.2D + 1.0Ex	-4.06	94.8 × 38	2-#8	11-#8 (the shell slab's reinforcement design)	Yes
18		Lattice beams at the low part of the shell (elevation: 15–17 m)	1.2D + 1.0Ey	-7.68	94.8 × 35.9	2-#8	10-#8 (the shell slab's reinforcement design)	Yes
19		Low part of the edge column(elevation: 17–18 m)	1.2D + 1.0Ey	10.28	115 × 35.9	3-#8	12-#8 (the shell slab's reinforcement design)	Yes
20	Shell N2	Edge beam along the ridgeline	1.2D + 1.0Ey	-10.49	25 × 60	3-#9	3-#9	Yes
21		Pin joint-to-shell boundary	0.9D + 1.0Ey	13.30	80 × 50	2-#9	2-#9	OK
22		Upper part of the edge column adjacent to the fixed connection	0.9D + 1.0Ey	4.79	110 × 27.5	1-#10	9-#10	OK
23		Middle part of the edge column adjacent to the fixed connection	1.2D – 1.0Ex	9.62	110 × 47	2-#10	17-#10	OK
24		Upper part of the edge column adjacent to the shell's outer surface	1.2D+1.0Ey	11.43	110 × 27.5	3-#9	5-#9	OK
25		Middle part of the edge column adjacent to the shell's outer surface	0.9D + 1.0Ex	11.31	110 × 30	2-#9	10-#9	OK
26		Lower part of the lattice beams adjacent to rigidly connected edge columns	1.2D + 1.0Ey	4.80	66.5 × 40.7	1-#8	1-#8	OK
27		Lower part of the lattice beams adjacent to the outer surface of the edge column	1.2D + 1.0Ey	2.32	38.3 × 39.1	1-#8	1-#8	OK
28		Low part of the edge column (elevation: 0–1 m)	1.2D – 1.0Ex	-11.08	110 × 40	2-#11	18-#11 (the shell slab's reinforcement design)	OK
29		Lattice beams at the low part of the shell (elevation: 1–3 m)	1.2D – 1.0Ex	-11.59	94.8 × 42.4	2-#9	13-#9 (the shell slab's reinforcement design)	OK
30		Lattice beams at the low part of the shell (elevation: 3–5 m)	1.2D – 1.0Ex	-10.73	94.8 × 46	2-#9	11-#9 (the shell slab's reinforcement design)	OK
31		Lattice beams at the low part of the shell (elevation: 5–7 m)	1.2D – 1.0Ex	-17.35	94.8 × 49.5	3-#9	9-#9 (the shell slab's reinforcement design)	OK
32		Lattice beams at the low part of the shell (elevation: 7–9 m)	1.2D – 1.0Ex	-18.95	94.8 × 53.2	3-#9	8-#9 (the shell slab's reinforcement design)	OK
33		Low part of the edge column (elevation: 9–10 m)	1.2D – 1.0Ex	-25.13	110 × 60	3-#9	10-#9 (the shell slab's reinforcement design)	OK

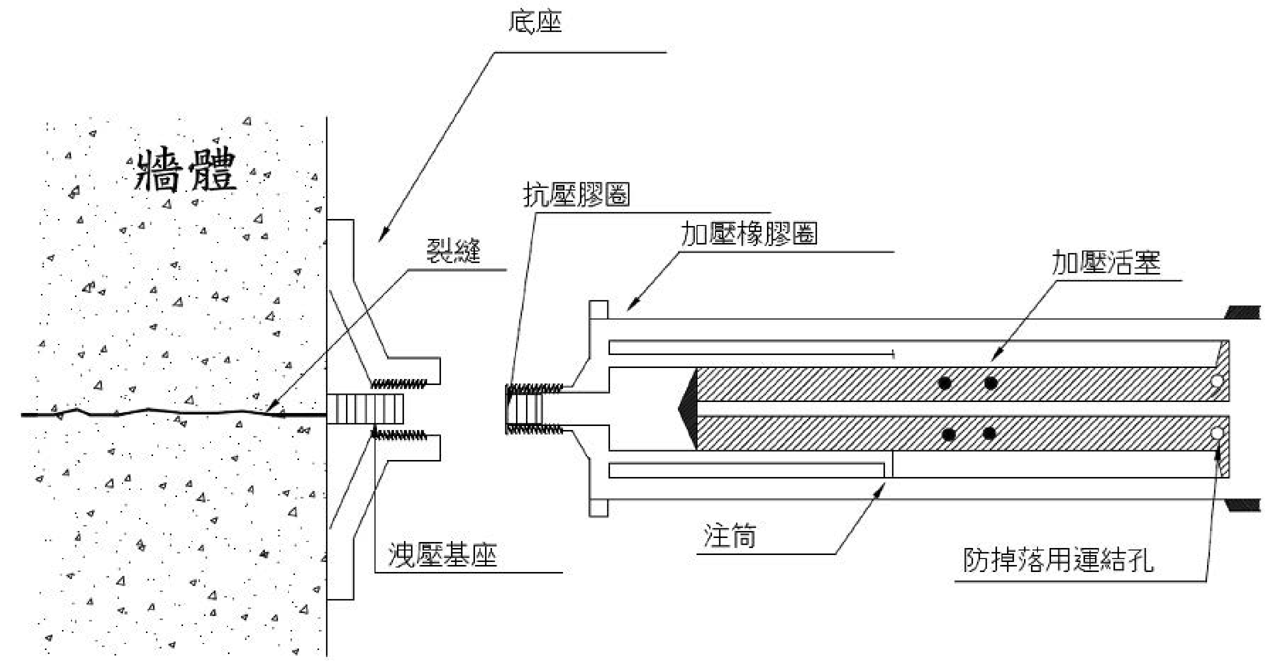
Conclusions and Repairing Recommendations

According to the above structural safety analysis of Luce Chapel, the cross-sectional size and reinforcement arrangement of each structural component satisfy the relevant stipulations, in which require the shear and bending capacity to endure a magnitude 6 earthquake. In addition, the concrete strength test indicated that the actual average compressive strength of the concrete is greater than the original design strength (i.e., 4000 psi). Therefore, this study proposed to repair particular local damages rather than reinforcing the overall structure system. Local damage conditions of the chapel structure primarily comprise crackings of RC beams and slabs, reinforcing steel corrosion and exposure, and minor local concrete damage and spalling. This study recommended the following repairing and reinforcing solutions for these damage conditions.

1. Crack Repairing Recommendations

Most cracks of the Luce Chapel were earthquake-induced micro-cracks and cracks caused by inadequate concrete protection layers and reinforcing steel corrosion. The distribution of these cracks is elaborated in Section 3.2.2. This study recommended applying epoxy injection to repair this type of cracks (Fig.4.107). Epoxy injection forces resin-based sealer into concrete cracks to repair and restore the load-bearing capacity of the concrete.
A procedure was recommended to perform epoxy injection:

1. Surface preparation: Use a steel wire brush or electrical grinder to smoothen a 30-cm-wide area around the crack.
2. Injection ports: a. Arrange the ports 30-cm apart along the length of the crack.
   b. Use a special adhesive to seal the bases of the ports to the concrete surface.
   c. Apply the adhesive around the bases of the ports to prevent leakage under the pressure of injection.
3. Adhesive hardening: Visually inspect the adhesive effectiveness around the bottom of the port bases and allow the adhesive to cure for 24 hours.
4. Epoxy injection: a. Prepare an epoxy-hardener mixture with a mixing ratio of epoxy and hardener should be 2:1.
   b. Fill the injection cartridge with the epoxy-hardener mixture and attach the injection fitting to the injection port until it clicks into place. Next, check whether the port base remains sealed to the concrete surface.
   c. Inject the epoxy-hardener mixture after the injection cartridge is steadily held in place with rubber bands.
   d. Observe the injection process and continue to inject until the mixture stops filling the crack.
   e. Use no more than 3 sets of rubber bands, which weighs 1 kg per set.
5. Epoxy curing: a. After injecting epoxy to the last port, a portion of epoxy will remain inside the cartridge tube. When the portion of epoxy cures, invite the architect to inspect the repaired cracks before the cartridge fitting is removed from the



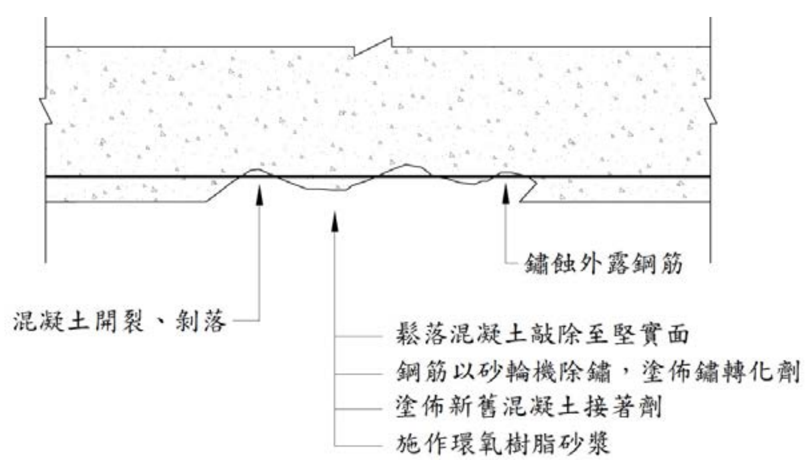
4.107 Illustration of epoxy injections to repair a crack on a concrete wall

injection port.
   b. Carefully remove the cartridge fitting from the injection port to avoid damaging the concrete surface and the injected epoxy mixture in the crack.
6. Surface recovery: a. Use an electrical grinder to smoothen the repaired surface.
   b. Prime and paint the surface to restore its original texture and color.

2. Local RC Damage of the Lattice Beams and Shell Slabs

Section 3.2.3 thoroughly describes the reinforcing steel corrosion and exposure that exist on the chapel's outer surfaces. To repair this RC damage, a procedure involving epoxy mortar, rust converter, and other measures was proposed and depicted as follows (Fig.4.108):

1. Remove the remaining plaster layer and the deteriorated concrete layer.
2. Clean up the dust, oil, and grease on the repairing surface.
3. Remove parts of the rust from the corroded reinforcing steel, and then apply a rust converter on the exposed steel. If sever steel corrosion or steel fracture exists, replace the damaged steel portion by welding new reinforcing steel.
4. Use compressed air to clean the cracks on the RC beams and slabs.
5. If water is continually seeping from the crack, the flow must be stopped before an epoxy injection.
6. Inject epoxy onto the repairing surface until the epoxy completely covers the exposed steel.
7. Let the epoxy cure for 24 hours before the injection nozzle is removed, and then sealing the nozzle hole by filling epoxy. Non-shrink cement mortar should be used to repair sever concrete spalling or RC damage situations.
8. Apply a thin layer of epoxy mortar over the repaired surface to protect the surface.
9. Recover the pre-damage appearance of the repairing surface.



3.108 Illustration of repairing a RC slab (or beam) that has reinforcing steel corrosion

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5. Research on the Conservation Methods of Wooden Objects in the Luce chapel

Introduction

1. Introduction

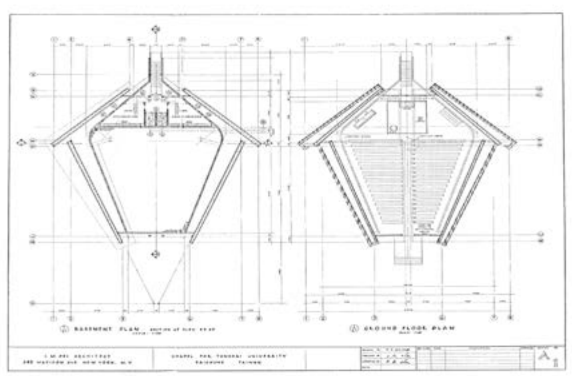
The concrete shell construction of the Luce Chapel, built in 1963, has made it one of the most representational contemporary architecture in Taiwan during the twentieth century. It's been more than 50 years since the completion of the construction. Several repair and renewal projects have taken place due to natural deterioration and functional requirements, and some changes have altered the original look of the chapel. Winning the "Keep it Modern" grants of Getty Foundation provided a chance for researchers to study the chapel, and design a proper conservation plan according to the standard of world heritage conservation, which shall allow the chapel to endure the course of history, and keep on bringing inspirations through its historical significance and cultural values for generations to come.

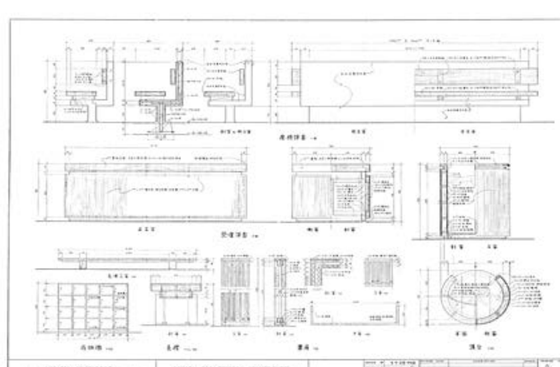
Besides the main architectural structure, interior decorations and portable furniture are also important parts of the chapel. Removing or altering the original furniture or decoration can easily change the atmosphere of the chapel. The coherence of the designer's original intentions will also be lost along the way. Therefore, it is crucial to include the wooden interior decorations and furniture in the conservation research project for a full-scale maintenance

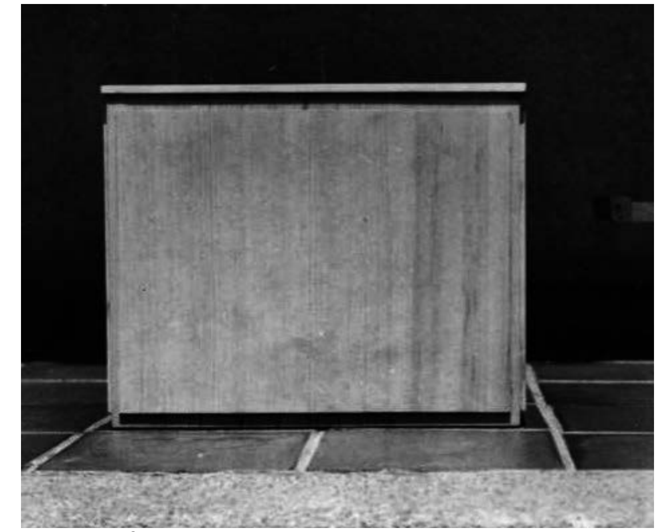
2. Research Plans

Unlike fixed structures, the furniture in the chapel could have been moved or added according to the need of its users. Therefore, as the research objectives, these objects had to be identified through studying the original design plans, photograph documents and memories of the chapel's users, following by a further categorization of the current furniture. After determining the research objectives followed the inspections of all the given objects. These inspections focused on the materials, production techniques, and the present condition of the objects. All the information were recorded and documented. Base on the acquired information, several experiments were conducted to develop future conservation and maintenance plans.


5.1Current Condition of the Chapel


5.2 Floor plan of the chapel's ground floor


5.3Furniture design


5.4 Picture of the pulpit sample


5.5 Picture of a pew sample at the congregational area Furniture design

Results

1. Inventory of the Wooden objects

Status and plans

The current wooden objects in the chapel are classified in two categories, 1) fixed wooden decorations, such as the wooden paneling along the shell walls, the altar and the floor. 2) Moveable furniture, such as pews and pulpit, etc. However, there are several differences between the present arrangement of these objects and the original design plan.

According to the floor plan, the ground floor of the chapel can be divided into two areas: the chancel and the nave (Fig.5.2). In the original design, the front of the chapel was to have a rectangular chancel with a communion table and a round pulpit in the center. At the left and right side of the rectangular chancel were to have fenced off seating areas with pews. For the nave, originally the two sections of parallel pews were to be made of concrete with wooden panels on top of the surface (Fig.5.3). Moreover, the altar and pulpit were both to be all constructed out of wood with wooden panels as the decorated surface. (Fig.5.3) However, in the photographs taken by C. K. Chen during construction stage, the pulpit design was change into a smooth rectangular cube (Fig.5.4), and the original concrete structured pews were replaced with a sheer wooden structure sample (Fig.5.5).

The rectangular chancel is not the current adoption, but the fenced off seating arrangement remains the same at the left and right of the chancel. In addition, the number of rails, chairs and pews were increased, and staircase was added to the choir section. The altar and the pulpit are decorated with simple smooth veneer, while the pulpit remains exactly the same as the pulpit sample photoed by C.K. Chen. The nave section keeps the original parallel pew arrangements; however the structural material was changed from concrete into wood, and the number of bench rows are reduces from 19 to 16.

The furniture plan demonstrates the simplicity of the design in style and structure, which coincides with the architectural style of the chapel. The characteristic of simplicity is also visible on the appearance of the furniture, making the added furniture easily distinguishable.

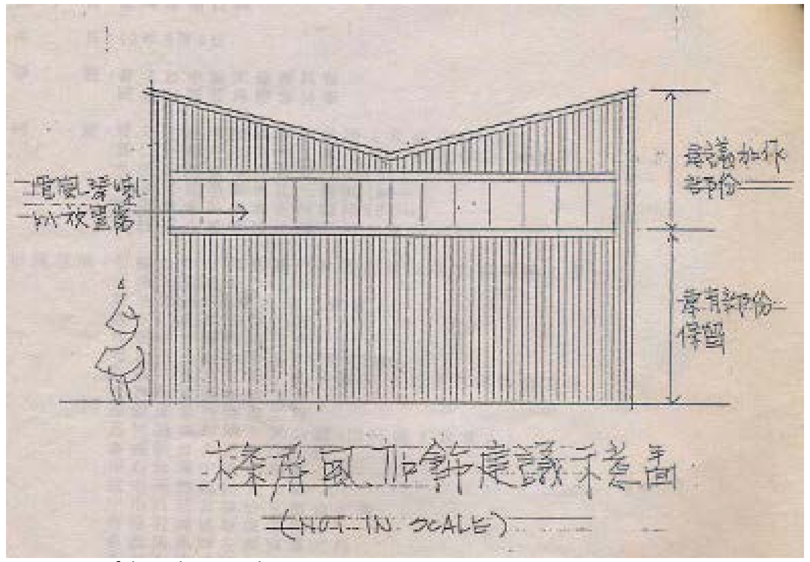
Table 5-1 The repair record of interior wooden furnishings of the chapel

Time	Title of construction	Notes
1992/3	Carpet Renewal	The carpet was changed
1993/10	Repair Project of the Luce Chapel	Extending the surface of the screen to cover the speakers of the organ. The carpet was also changed
2000/4	Repair the Altar Table of the Chapel	The veneer of the pulpit and altar table were renewed
2002/10	Renewal of the Carpet on the Congregation Area	Carpet Renewal
2003/08	Repaint and Repair the Wooden Furnishings in the Chapel	The wooden furnishings were repainted, and metal components were changed.
2011/12	Flooring Renewal	The original wooden floor was replaced with plastic wood grain wear-resistant flooring
2015/4	Replication of the Original Screen in the Chapel	Remove the old screen and restore 拆 the original screen design. The original design was replicated to store the new organ speakers.

Comparisons between photographs and maintenance records

In addition to obtaining information from the design drawing, yearbook photos and other photo records provided by the university alumni also helped in identifying the types of wood used to furnish the chapel and the original display of furniture. Repair records of the general affair office of the school provide the alternation records on arrangement and display of furniture and wooden furnishings. The available repair records with dates and repair content are as shown in Table 5-1 The repair record indicates the change of the flooring from wood to wear-resistant surface. The screen was extended in height in 1993, and the design plan of the screen extension was found in the repair record (Fig.5.6). The veneer finish on the wooden furnishings and metal components were all fixed and repaired.

The change of the chapel interior can be observed from the photos of the early records. In the inauguration photos, the floor was made of wooden panels, and the platform was without microphone devices (Fig.5.7). The current pulpit has been equipped with microphone devices (Fig.5.8). In the 1964 yearbook, the screen was still the original rectangular design the photographs (Fig.5.9); and it had remained the same in the 1968 yearbook. However, by 1968, the floor was changed into lozenge-patterned carpet (Fig.5.10). In 1977, the floor was changed into a single color red carpet, and the furniture finish kept the actual wood color.

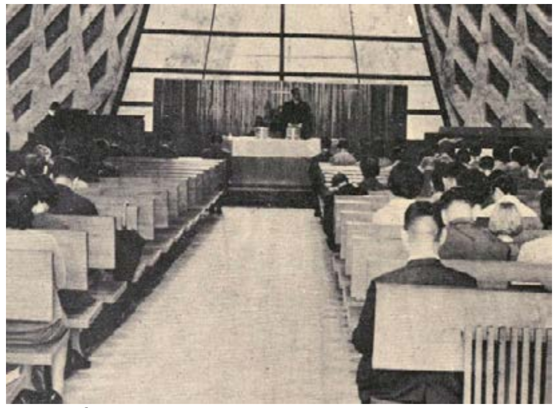


5.6 Picture of the pulpit sample

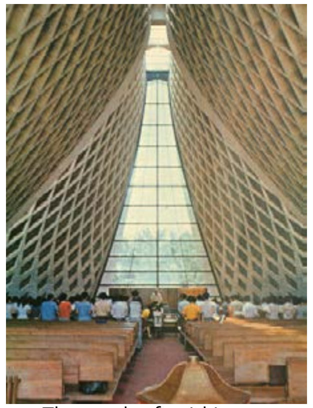
5.7 The inauguration of the chapel

4.8 Current state of the pulpit

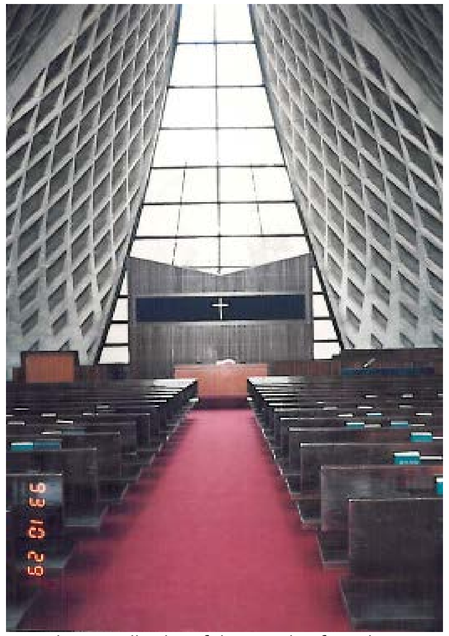
5.9 The original wooden flooring was still visible in 1964



5.10 The floor was carpeted in lozenge pattern by 1968



5.11 The wooden furnishings were in natural wooden color in 1977



5.12 The overall color of the wooden furnishings were changed in 1993

The fence decoration on the back of the last row has now been painted over with a coat of auburn paint (Fig.5.11). In the photo taken in 1993, a black and inverted v-shaped extension was added on top of the screen to cover the organ speakers. Furthermore, the color of the pews became dark brown and the natural wooden texture became barely visible (Fig.5.12).

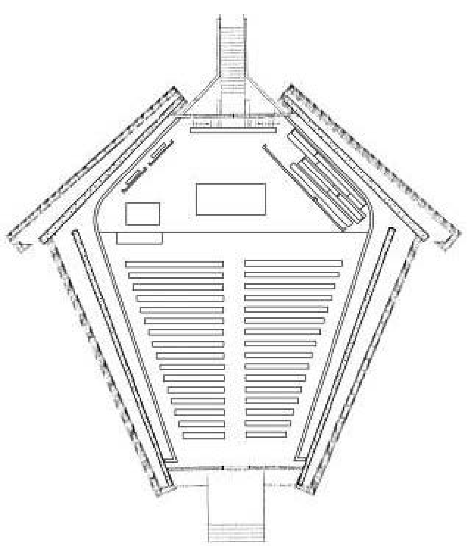
The hat-shaped object in Fig. 5. 11 was the offering box, which is now stored in the archive of the school's library. The existence of this item can be traced back to the founding year of the university, which was before the construction of the chapel. Therefore, the style of the box does not correspond the design of the church and is not included in the research objectives.

After the inventory, 53 wooden items were found to be directly relevant to the chapel, and are listed in following table.

Table 5-2 List of Wooden Items

Mobility	Title of Component	Number of items	Arrangement	Notes
None	Stub wall furnishings	2	At the chancel and the nave	
None	Screen	1	Chancel	
Yes	Fence	4	Chancel	
Yes	Seats	7	Chancel	2 high back chairs, 5 pews
Yes	Seating Pedestals	5	Chancel	2 low pedestals, 3 high pedestals
Yes	Pulpit	1	Chancel	
Yes	Altar Table	1	Chancel	
Yes	Pews	32	Nave	
Total			53	

The present furniture display in the chapel is indicated in Fig.5.13. This plan shows the positioning of the furniture without the actual ratio of the items.
During the inventory, we found the pew placed at the northern end of the chancel to be identical to the pew sample in C.K. Chen's photo. This pew is similar to the other pews in the chapel with minor differences in detail.
This pew is not directly attached to the backrest frames, nor is it fixed with any metal joints in between (Fig.5.14、Fig. 5.15). The slots behind the pews serve as Bible racks and communion cup holder. The frames were glued, unlike other pews, which were nailed together (Fig.5.16、Fig.5.17). The communion cup holders on this pew have circular holes on the wood planks, instead of indentations on top of the side edges of the slots (Fig.5.18Fig.5.19). There are screw grooves to connect the seat and pew legs (Fig.5.20、Fig.5.21), which were designed to simplify the manufacture process during mass-production. The design of the communion cup holders might have been changed due to the demand of quantity. Since a pew does not have a limited seating arrangement, the original design of drilling holes through wooden planks would have limited the usage while creating indentations at side edges of the seats better fits the user requirements (Fig.5.22、Fig.5.23).



5.13 Current Interior Arrangement

5.14 There's a gap between back of the pew and its frame.

5.15 The back of the pew is directly attached to the frame.

5.16 The frames were glued together

5.17 The frames on the back of the pew were fixed together with nails.

5.18 Circular holes were drilled through to serve as communion cup holders.

5.19 Wood plank indentations at the sides serve as cup holders.

5.20 There is an indentation for screw at the connecting points of the legs and the seat.

5.21 The screw is exposed on the surface of the chair leg.

5.22 The original communion cup holder can only hold one cup per hole.

5.23 The new communion cup design can hold more than one cup.

5.24 Inspecting the surface of the objects

5.25 Recording on the registration chart

2. Cuurent Preservation Conditions

Before making a repair plan, the research objects should be examined in detail to study the production method and current condition of these items. It is also necessary to keep all the observation records as future resources. Regular checks on the maintenance records are essential for overseeing the preservation condition of these items and taking timely actions to prolong the life of these objects appropriately.
The registration chart documented the basic information and preservation condition regarding these objects, along with photos taken at different time period. Therefore, it serves as an important document to identify the items. It is an important resource, which marks the changes of the items throughout the course of history (Fig.5.24, 5.25).
Sometimes, it is hard to deliver accurate information solely through terminologies used in the registration chart; therefore, photos along with illustrations were added as references for relevant personnel and others who are interested in learning about wooden artifact and its aging phenomena. The condition of this research objectives can be categorized in 3 three groups: paint finishes, wood floor, and subsidiary materials.

Paint Finishes

Paint finishes are coatings of paints on the surface of furniture and wooden furnishes used for protection or decoration purposes. According to the painting order, the coatings can be divided into primer and finish coat. A primer serves as the foundation paint. It seals wood pores and changes wood colors. The finish is an outer transparent or color paint, which enhances the final result and forms a waterproof surface on the wood.

Paint deterioration usually occurs during usage, production process, and thermal expansion and contraction. The most common paint deterioration is peeling (Fig. 5.26), which is caused by various factors. It might be the incompatibility between the paint and the object or the lack of elasticity of the paint, which results hollow (Fig.5.27), cracks (Fig.5.28), desquamation (Fig.5.29), flaking and other conditions. These conditions would result a space between paint layer and the object, allowing water vapor permeation, and create atomization effects. Atomization can also be the result of chemical reaction within the paint, instead of the influence of water vapor. The atomized condition of the paint on the pews; however, is caused by overexposure under the sun (Fig.5.30).


5.26 Peeling paints


5.27 Hollows under paint layers


5.28 Cracks


5.29 Desquamation of paint


5.30 Atomization


5.31 Tear and wear


5.32 Scratches


5.33 Stain


5.34 Biological metabolism and tissue residue


5.35 Blue-tack


5.36 Tape


5.37 Marks of peeling


5.38 Cotton fiber


5.39 Deliberate damages


5.40 Touch-up paint


5.41 Tape Marks

The paint deteriorations most likely to result from daily usage is wear and tear (Fig.5.31), which is commonly found in areas of frequent contact, such as seats and backrests. These parts of the seat are usually left with scratches (Fig.5.32). In addition to the general deterioration, damages can also be caused from human or animal movements, such as various stain marks, metabolism and tissue residues (Fig.5.34). Additional causes are adhesives, such as tapes (Fig.5.35) and blue-tack (Fig.5.36) used for event decorations. Marks of peeling (Fig.5.37) and cleansing cotton were left on the pews in the process of adhesive removal (Fig.5.38). There are even marks of deliberate damages (Fig.5.39). At the same time, we can also find marks of previous mending, such as touch-up painting (Fig.5.40) and tape marks (Fig.5.41).

There are also painting failures such as bubbles, blisters (Fig.5.42), and sagging (Fig. 5.43), which are only aesthetically disturbing without any fundamental damages to the paint.
The analyses of paint deterioration are as shown in Fig.5.44. According to the bar chart, deteriorations of these items mostly resulted from daily usage. These major deteriorations include dirt, stains, wear and tear, scratches, cracks, absence, etc. Some of the items, such as the high back pews, pedestals, altar and pulpit contain neither peelings, nor repairing traces. Two high back pews are kept in good condition due to low usage, though one of them is different in appearance and color. It was probably made in a different time period. The paint on top of the pedestals is a thin coat rigidly connects to the wood; therefore, there is no peeling on the pedestals. "Others" at the right end of the charts indicates abnormal deteriorations such as hollows, sags, bubbles and blisters, cotton fibers, deliberate destruction, etc. These are not normal conditions to be observed on average objects; thus they were classified as the "others" category with annotations in the records.


5.42 Bubbles and blisters


5.43 Sagging

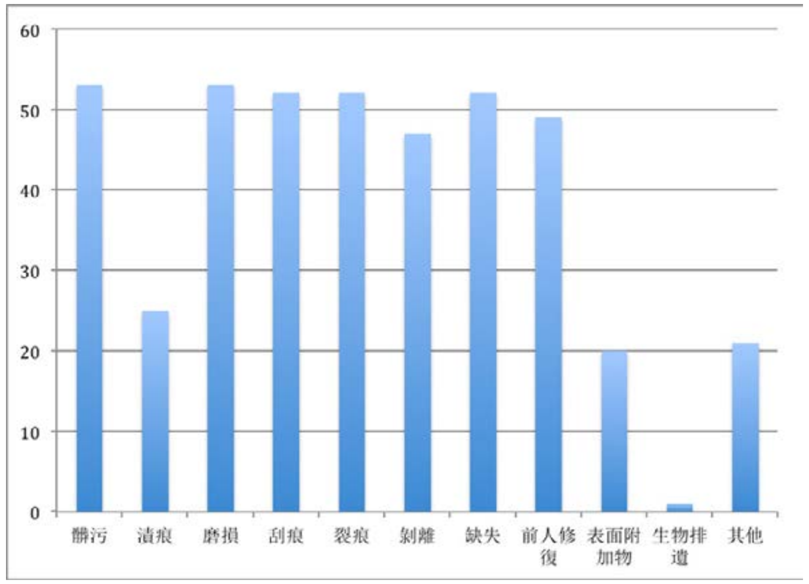


Fig.5.44 Paint Deterioration Analysis

Wood

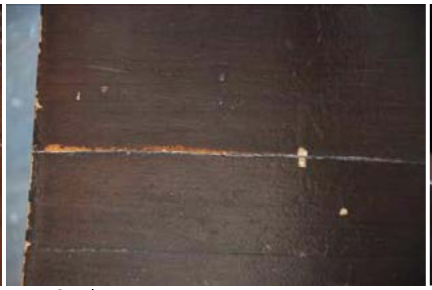
Wood substrates can expand or shrink due to the effect of temperature and humidity. Subsequently, the expansion and shrinkage would be carried through layers of paint, and diminish the protection of coating. Furthermore, normal usage would also cause wear and tear (Fig.5.45) along scratches (Fig.5.46) and pressure marks (Fig.5.47). When wood substrates go through drastic humidity change,


5.45 Wear and Tear


5.46 Scratches


5.47 Pressure marks


5.48 Distortion


5.49 Cracks


5.50 Fracture


5.51 Loose components


5.52 Absence of nails


5.53 Water Stain


5.54 Chewing gum


5.55 Stickers


5.56 Electrical facilities

distortion (Fig.5.48), cracks (Fig.5.49), fracture (Fig.5.50) and other deterioration would occur. Parts of the stapling components can be loosen (Fig.5.51) or absent (Fig.5.52) as external forces press the structure during usage.
No paint was found under the seat. This craftsmanship not only saves coats of paintings, but also enables the wood to breathe. However, this also means no water resistant function exists at the bottom of the pews. Therefore, damp stains and watermarks (Fig.5.53) were found underneath. As a blind spot, these corners also become places where users left their garbage, such as chewing gum (Fig.5.54), stickers (Fig.5.55), etc. Electrical facilities were also found to be hidden under the seats (Fig.5.56).


5.57 Slots beneath the seat


5.58 Holes for electric wires


5.59 A hole1 for electric network


5.60 Pinholes


5.61 Patch marks


5.62 Natural defects


5.63 Loose components


5.64 Repairing marks on the sidewall

Slots were added to the bottom of the first row pew as Bible holders. (Fig.5.57). There are holes for electric wires on some of the pews to equip interpretation devices, which were added according to the needs of foreign faculty, staff and guests (Fig.5.58、Fig.5.59). Beside these marks, pinholes from event decorations were also found along the aisle side of the pews (Fig.5.60).

When it comes to wood works, natural defects are usually inevitable. Therefore, minor repairing marks are often found on the front and back of a wood chair (Fig.5.61). Wood fillers are used to patch porous surfaces, and timber for the seams on the backrest. Currently, there are still some natural defects hidden in the inconspicuous corners, places such as pew legs and the bottom of the seats are in need of repair (Fig.5.62). Besides the repairing marks caused during manufacture, subsequent repair for damages caused by normal usage were also discovered. Nails were used to fix loose cup holders (Fig.5.63), and partial sidewall damages (Fig.5.64).

Currently the wood damages caused by wood-boring beetles are minor. The main cause of insect pest is beehives built in the wood pores (Fig.5.65), which exist on the unpatched surface of blind spots underneath the seats. These unpatched areas have become the perfect environment for parasites. Marks of infestation were found on one of the pew legs (Fig.5.66). According to the infected condition, worm eggs were probably laid in the timber before the manufacture of the pews, and eventually underwent metamorphosis and bit through the wood surface.


4.65 Beehives

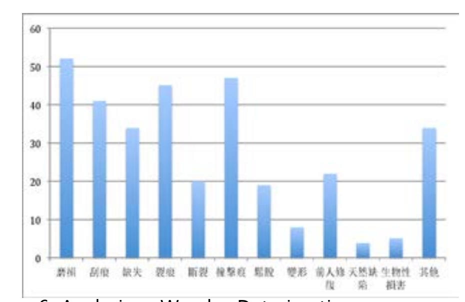

4.66 Mark of infestation

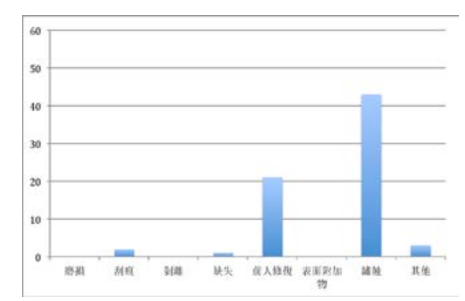
4.68 Memorial Panel


4.69 Rusts


4.70 Flat-head screws were replaced with stainless Phillips screws


4.71 Missing screws


4.67 Analysis on Wooden Deterioration


4.72 Deterioration of Attachments

Analyses on wooden deterioration are as demonstrated in Fig.5.67. The main deterioration is caused by usage. Wear and tear was found on most of the wooden objects. The paint finish has minimized the damage of scratches; however, the quality of timber is another factor that would affect the deteriorating conditions. Some woods are more likely to be affected by humidity and thermal expansion and contraction, which would create cracks, while some wood grains are simply more likely to break. Thus, there are no particular pattern or rules to be followed. The last bar on the chart indicates artificial damages such as surface attachments and nail holes. Annotations are included in the review sheets.

Attachments

A small quantity of supplementary materials is classified as attachments, which include the engraved memorial stone panel and metal setting mechanism.

The stone panel is in a good condition with minor scratches on the surface (Fig.5.68). The metal components of structural fasteners are mostly rusted (Fig.5.69). Some were changed from flat-head screws to stainless Phillips screws (Fig.5.70). Some fasteners are missing screws due to insufficient final check after replacements (Fig.5.71).

The deterioration conditions of attachments are indicated in the following bar chart (Fig.5.72). Most of the attachments are made of metal with rust being the main deterioration. Nearly half of the attachments were replaced; therefore repairing damage is another major factor of degration.

Only one item is missing screws after replacement. Scratches are also only found on the stone memorial panel. Other deterioration conditions of attachments such as stains and distortions are found on top of stone and metal component, respectively. Annotations are noted in the review sheets.

Over all speaking, the wooden components in the chapel are in good condition, and no urgent recovery is necessary. Major conservation procedure should focus on repainting, reinforcement of wooden structures, as well as reinstalling missing metal components.

Table 5-3 The Usage of Wood in Wooden furniture and furnishings

Title of Component	Wood Species	Functions
Communion Table	Chamaecyparis formosensis Matsum.	Basic Structure
	Tectona grandis f.	Surface Decoration
Pulpit	Chamaecyparis formosensis Matsum and Tectona grandis f.	Basic Structure
	Tectona grandis f.	Surface Decoration
Screen	Chamaecyparis obtusa S. et Z. var. formosana (Hay) Rehd.	Assembly of Wood Planks
High Back Pew	Tectona grandis f.	Assembly of thick wood slabs
Choir Staircase	Shorea spp.	Assembly of Wood Planks
Choir Pews	Tectona grandis f.	Assembly of thick wood slabs
Choir Stalls	Chamaecyparis obtusa S. et Z. var. formosana (Hay) Rehd.	Assembly of Wood Planks
Sidewalls	Shorea spp.	Assembly of Wood Planks

3. Examination and Analyses

A good recovery plan with proper repairing materials can only be made with careful examinations and analyses of the current materials. The research items are mainly wooden furnishings with coatings of paint, thus wood identification is crucial for the research. Professor Lin, Jen-Cheng, the leader in the Lab of Cultural Assets in Taiwan, conducted the examination of wood species and quality. Layers of surface paint were analyzed through the slicing method and Fourier Infrared Spectroscopy. The slicing method is introduced to examine the composition and the layers of paints. The wood identification and slicing methods are explained as follows.

Wood Identification

The wood grains of various components were examined through visual observation and magnifier. Observations of relevant traits, such as growth rings, texture, color and scent were distinguished and recorded as the reference for further inspections. Samples of wood debris were also collected for further investigation. Micro observation of features such as wood cells, the arrangement and distribution of tree vessels, and longitudinal parenchyma, etc. are the traits to highlight differences between wood species.

Four species of wood were found in the wooden furniture and furnishings in the Luce Chapel. They are Chamaecyparis formosensis Matsum, Chamaecyparis obtusa S. et Z. var. formosana (Hay) Rehd, Tectona grandis f., and Shorea spp. The analyses and the usage of the wood are as shown in Table 5-3.

Precious cypress (Chamaecyparis Taiwan and Taiwan cypress) were used in the making of the communion table, pulpit, screen, and choir stalls. These wood materials were placed in the center of the chapel, where sermons take place. The choice of wood conveys the design concept of utilizing these precious woods in Taiwan to elaborate the beauty and solemnity of the chapel.

It is worth mentioning that a high proportion of pews were made of teak slabs, rendering solidness and beauty in texture. Given the high stability and solidity of teak, durability and life span of the furniture would also amplify. The pews made of teak are in a good condition in terms of appearance and stability. Using teak as the substrate material of the pews was certainly a thoughtful and prudent decision in design.

The minor furnishing areas, such as choir staircases, sidewalls along the shell walls were made of lauan, a cheaper substrate material, which is lower in quality. The use of lauan not only reduces manufacturing costs, but also enhances strength and reduces deterioration of other timbers.

5.73 Recording wood grains

5.74 Visual observation of wood grains

5.75 Teakwood was used as the veneer on the communion table

5.76 Taiwan cypress was used to built the main structure of the communion table

5.77 Front view of the communion table

5.78 Current state within the communion table.

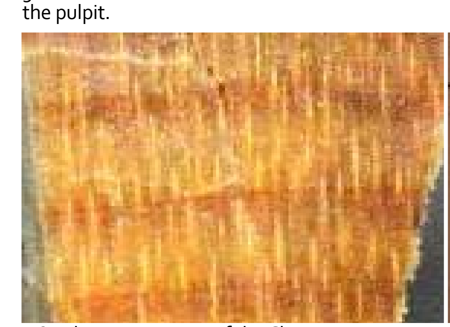
5.79 The pulpit's current inner condition

5.80 Current state of the pulpit's facade

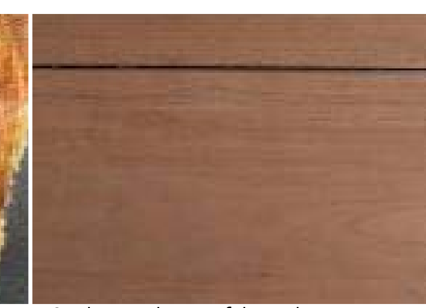
5.81 Teakwood was used to form the structure of the pulpit.

5.82 Teak was used to veneer the pulpit.

5.83 The cross section of the Chinese cypress used for the communion table.



5.84 The cross section of the Chinese cypress used for the pulpit.

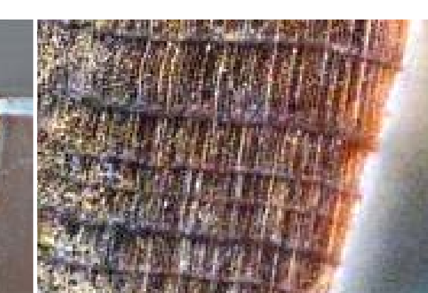


5.85 The wood grain of the teak staircase

5.86 The footstool under the pulpit

5.87 Wood grain of Taiwan Cypress.

5.88 The Screen made of Taiwan cypress has marks of black and brown paint.



5.89 The cross section of Taiwan cypress fiber used to make the choir stall.


5.90 The cross section of Taiwan cypress used to make the screen.


5.91 Current condition of the teak pews


5.92 The structure of the teak pews


5.93 The front wood grain of the teak pew slab

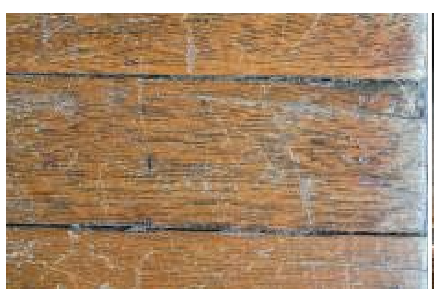

5.94 The back wood grain of the teak wood backrest


5.95 The wood grain of the teak pews


5.96 Current condition of the teak choir seats


5.97 The cross section of the teak used to produce choir seats.


5.98 The cross section of teak pew slabs

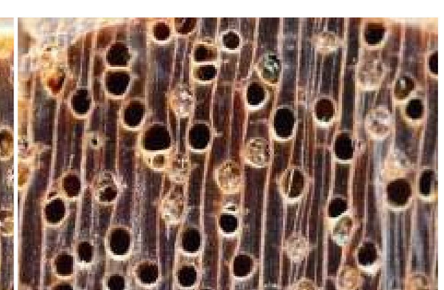

5.99 Apparent wear and tear along with paint deterioration of a lauan wood surface


5.100 The wood joint craftsmanship of the lauan wood staircase


5.101 Wood grain of lauan wood planks


5.102 Sidewalls made of lauan wood planks


5.103 The cross section of the lauan wood at the side walls.

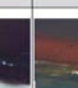
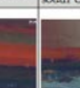
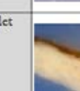
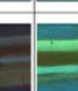
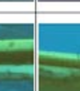

5.104 The cross section of the lauan wood choir staircase.

The original flooring of the chapel was identical to the material used in the old gymnasium. Comparisons between the floor and choir staircase were made, and were both confirmed to be lauan wood. As a cheaper type of timber, which can also easily be obtained, restoration of the original floor is recommended.
In addition, in order to create storage to place the organ speakers, the school decided to restore the original screen design by removing the upper V-shape section of the screen. This requires dismantling the screen as to create space for speaker storage. In order to preserve the original object, the school dismantled the screen and replaced the cypress screen with a replica made of plywood and cypress. The original screen components are kept properly in the wood warehouse on campus.

Cross section Analysis

From the wear and tear of the surface paints, marks of repaints were observed. The repaint frequency and ingredients can be determined through analyzing the paint layers.
For the layer analysis, paint samples were first taken from the hidden corners of the object to minimize the effect on the overall appearance, and to extract relatively complete coatings. Samplings were polished with resin and analyzed under a microscope with visible light and ultraviolet light.
Result:
Layers of primers and finishes vary in components. The painters might had different standards of coating. All items other than the high back pews at the south-west corner and the sample pew were repainted with a coat of red paint. Both the high back pews and the sample pew have clear wood grains identical to the ones found on the photos of the original pews. Therefore, these two objects can be taken as a standard for wooden surface restoration.

Table 5-4 Analysis on Cross sections of Wooden Furnishings

Title of component	High back pew at the South-West corner	Sample Chair	Screen at the North-West corner	Side Walls	The back of the first pew at the south end	The front of the backrest of the first pew at the south end	The front of the backrest of the 15th pew at the south end	The front of the backrest of the 16th pew at the south end	The vertical wood plank decoration on the backrest of the 16th pew at the south end	The horizontal wood plank decoration on the backrest of the 16th pew at the south end
Visible light										
Ultraviolet light										
Layers of Paint	2	8	3	8	4	4	8	4	10	6

Follow-up research and Maintenance Suggestions

1. Follow-up research

This research did not examine the ingredients of paint layer due to the limit in budget and given time frame. Before restoring the surface paint, chemical analysis needs to be conducted in order to define the ingredients of the current paints. Observation of the current state of paints shows that the original painting materials were not wear resistant. Therefore, after conducting subsequent chemical analysis and ingredient identifications, a different and stronger substance should be chosen to enhance the protection. Additional tests should also be performed before applying a new coat of paint finish.
Furthermore, repairing the surface paint also involves a method of removing damaged layers. Both physical polishing and chemical solvent scraping can be used as methods of solution. There are advantages and disadvantages for both methods. Polishing can harm the wood and it does not clean the corners well, but the rough polished surface is better for adhesion of subsequent coating. On the other hand, chemical acidity could cause bleaching or residues. Therefore, removal method should be determined after tests and evaluations.

2. Maintenance suggestions

Restoration
The chapel is a functional facility in which interior wooden furniture and decoration must be coincide with its missions. The inspection results indicate the components in need of repair as the following: the surface paint, the damaged wooden structure and metal components.
The worn out paint surface indicates the history of the object. The protective paint is to prolong the life span of the objects rather than maintaining the appearance or presenting its historical value. The worn-out paint should be removed before further paint is coated on the objects.
Wooden damages can affect the overall safety of an object. Condition such as: legs fracture should be replaced with the same kind of timber to ensure the stability of the chair. In addition, attachments such as chewing gums, stickers, holes and other natural defects should be removed and repaired to avoid further pest damages on the objects.
The missing metal components should be reinstated and properly fastened.

Property Inventory
The chapel does not have a property inventory at the moment. A property inventory would bridge the relations between the properties and the chapel, and effectively preserve the items with historical meanings to the Luce Chapel. Besides listing properties, the inventory also needs to be properly archived to prevent loss and damages of the records
This research has confirmed the original item in the chapel, and inspected the locations and present conditions of these items. Relative management personnel can use this research and the relative regulations of the university to create an inventory for the properties in the chapel.

Regular Maintenance
The fundamental approach to prolong the life span of any objects is regular inspections and proper maintenance. Appropriate tools with accurate cleansing methods can keep the objects in good state, and routine inspections ensure timely treatment of early damages. Other than routine inspections and proper documentations, a maintenance team with regular trainings, which educate relative personnel with the right understanding of lacquered wood, is also a key to successful maintenance and management.
Most of the wooden objects in the chapel are large and heavy, thus require a large amount of manual labors for rearrangement. Transport equipment can be purchased to reduce manual labor and avoid damages caused by improper handling.

6.

The Research on Luce Chapel Conservation The Investigation and Improvement Plan of Thermal Environment

Introduction

1. Background and objective

As one of the most representative modern architectures in Taiwan, Henry Luce Memorial Chapel in Tunghai University has been deteriorating over the years. Therefore, improvements considering functions, culture, and conservation have become significant tasks.

With a grant from the J. Paul Getty Trust in 2014, Tunghai University launched researches regarding comprehensive improvements, including studies on architectural construction, structure, building physics, facilities, etc. This chapter focuses on propositions regarding improving construction through analyses of thermal comfort and architectural energy saving, according to diagnoses on interior thermal environment and HVAC system.

2. The research team

Sustainable Building Design/Engineering Laboratory (SBDE Lab.) led by Associate Professor Yaw-Shyan Tsay, extending from BOHAS Lab. Established by Professor Che-ming Chiang, aims at issues within sustainable building design and building physics. Furthermore, researches by SBDE Lab. cover simulation of architectural thermal and humidity environment, indoor air quality, architectural acoustics, natural ventilation, green building materials, simulation and estimation of energy consumption, HVAC system, etc. Research methods involve onsite measurements, laboratory measurements, and quantized data simulation. SBDE Lab. commits to bring forward consultations corresponding with the vernacular characteristics, and combine both design and engineering profession.

3. Research methods

This proposal consists of the thermal environment adjustments, and suggestion on building facilities. Lowering the thermal load is the key to adjust thermal environment. By visualizing air flow with onsite measurements through CFD system, building dynamic energy simulation, and other data simulations, suggestions to architecture design are provided after analyzing the effect of lowering solar radiation heat and increasing natural ventilation. As for building equipment aspect, based on the lowered thermal load, air-conditioning equipment should not only reach the standard of energy saving and thermal comfort, but also coordinate with lighting, acoustic, and other equipment.

Challenges of Constructing Green Buildings in Taiwan

1. The climate and vernacular architecture in Taiwan

Architectures are for human inhabitation and usage; therefore, they should correspond to local climates. Architecture design faces the challenges of high temperature and humidity in Taiwan as it locates on the boundary between subtropical and tropical climate, where hot and humid weather blankets the island. Therefore, subtropical architecture designs should put sun shielding and ventilation to prior consideration. The forefathers of the land used architectural strategies such as taking available materials in the surroundings to encounter environmental forces to achieve structural strength and comfort. (Fig.6.1)

2. The movement of green building in Taiwan

The term "freezing" is a rarely used vocabulary in subtropical environments. Moreover, greenhouse effect and urban heat island effect are getting worse in the present day. The concept of sustainable living has been a thriving subject as the average temperature keeps rising. Therefore architecture design is challenged with issues such as architectural energy efficiency, and the concept of building sustainability, which have been discussed widely.

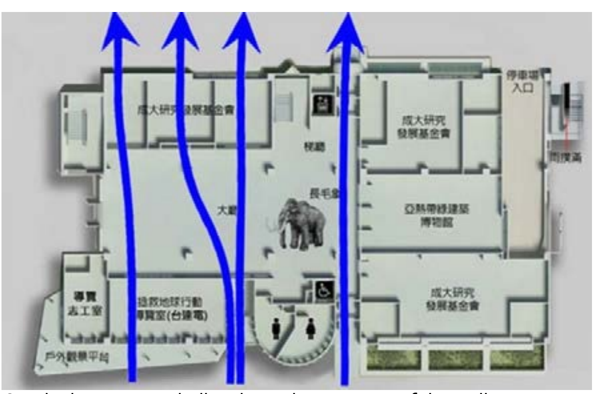
Sustainable buildings are architecture design based on human health and comfort, along with the harmonious coexistence with bio-system, and maintain the sustainability of human civilization. The Green Building Label in Taiwan was launched by National Council for Sustainable Development, which was established by Executive Yuan in 1995. The Architecture and Building Research Institute subjects to Ministry of the Interior, the leading role of architectural research and development. It established the Manual of Estimating Green Building and the Green Building Label in 1999. The Green Building Label established in 1999 evaluated seven labels, which were greenery measurement, water retention performance, regularly energy saving, CO_2 reduction, waste reduction, water resource, and polluted water purification. The present Nine Labels of the Green Building Estimating System were completed with the addition of biodiversity requirement and interior environment requirement in 2002. The Magic School of Green Technologies (MSGT), designed by Professor Hsien-Te Lin, who as the leading designer, reduced the architectural energy consumption to 35% of the original version by various design techniques, making MSGT a role model among Taiwan green buildings.

竹管厝 House Made of Bamboo and Soil | 石板屋 Stone House | 高角屋 Bamboo House

6.1 Vernacular Architecture in different parts of Taiwan

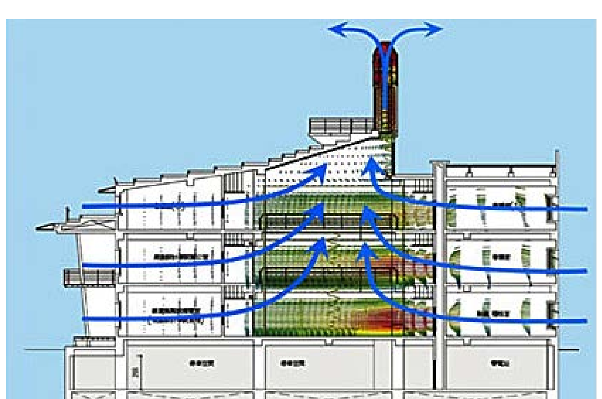
3. Design Strategies for energy conservation & thermal comfort

Take the Magic School of Green Technologies (MSGT) for example; its interior thermal comfort was enhanced with a long narrow hall, accompanying windows on two of the walls to increase ventilation. In addition, ceiling fans were installed to reduce the usage of HVAC (Fig.6.2). Moreover, in order to enhance ventilation efficiency, a roof garden was designed on top of the building to moderate the temperature of the architecture (Fig.6.3). The additional installation of a buoyancy-driven tower at the center of the roof, and a thermal chimney at Chung Hwa Hall also amplified the ventilation efficiency.

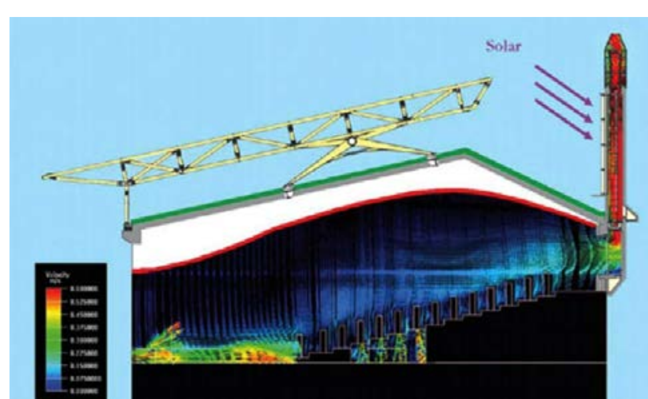


6.2 The long narrow hall with windows on two of the walls

6.3 The roof garden of MSGT



6.4 Simulation diagram of the buoyancy-driven tower



6.5 Air flow Simulationin Chung Hwa Hall

The Investigation of Thermal Environment

1. The current condition of Henry Luce Memorial Chapel

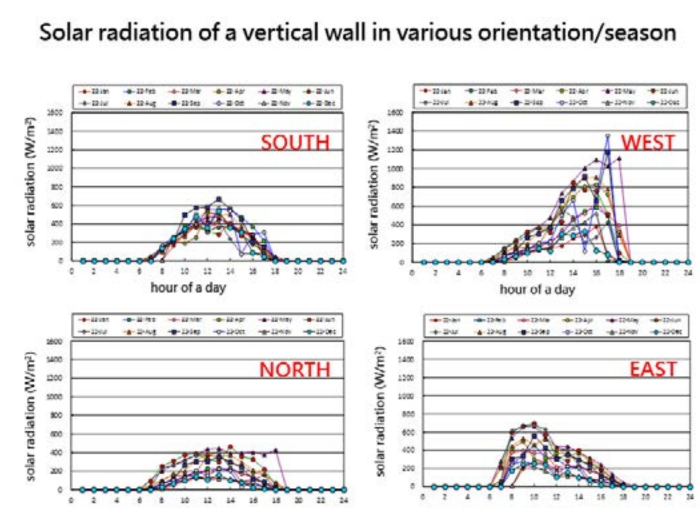
The Henry Luce Memorial Chapel has been a place of worship, assembly, wedding ceremony, etc. According to its users, the interior thermal comfort and ventilation generally drop considerably and the air becomes sultry when the crowd occupies the chapel by a certain degree. Low efficiency of natural ventilation decreases the interior heat load dissipation, which unavoidably leads to dependence on HVAC system. The air conditioner is turned on all year round. Even in mild temperature during spring and autumn, the HVAC system is still fully activated.

6. There are multiple methods and similar cases, which can be applied to solve the sultriness in the chapel. However, being one of the most symbolic modern architectures in Taiwan, the renovation of the Henry Luce Memorial Chapel requires minimum alterations with a maximum effect. Having this as the fundamental principle, this research endeavored to find proper strategies and solutions to improve ventilation and thermal comfort of the chapel.

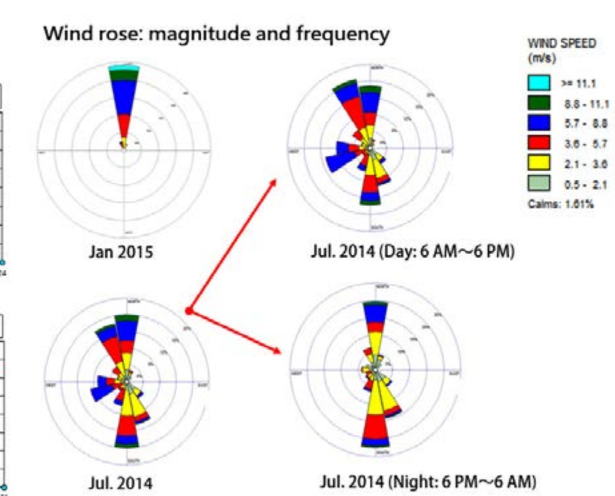
2. Solar Radiation

As a building with east-west openings without surrounding shading or vegetation, direct sunlight escalates the indoor heat load considerably.

The following Fig.s indicate solar radiation of a vertical wall in various orientations and seasons in Taichung (Fig.6.6). According to these Fig.s, solar radiation is at its highest on walls facing east and west during daytime from morning to afternoon. The solar radiation reaches its highest at 1400W/ m2 on the wall facing west. Therefore, having grand windows at the east and west end of the chapel introduces excessive thermal radiation, and the west opening is especially overheated.



6.6 Solar radiation in various orientation/season in Taichung



6.7 Wind Rose diagram of summer and winter

3. Natural ventilation

The above diagram are wind rose diagrams (Fig.6.7) featuring the wind data surrounding the Luce Chapel in July 2014 and January 2015. The July and January data were selected to represent the summer and winter wind field around the chapel respectively. According to those diagrams, the wind direction in summer it is mainly north-south with an aerage wind velocity of 3.9 m/s, while north wind mainly dominates in winter with an average wind velocity of 5.5 m/s. Moreover, when categorizing the July wind rose into daytime (after 6AM) and nighttime (after 6PM), the north-south wind clearly has a higher percentage of occurrence. Unfortunately, a regular north-south wind orientation, does not ventilate the chapel, which consists openings at the east and west end of the building. The shell walls at the north and south sides of the building nullify the natural ventilation brought by north-south winds.

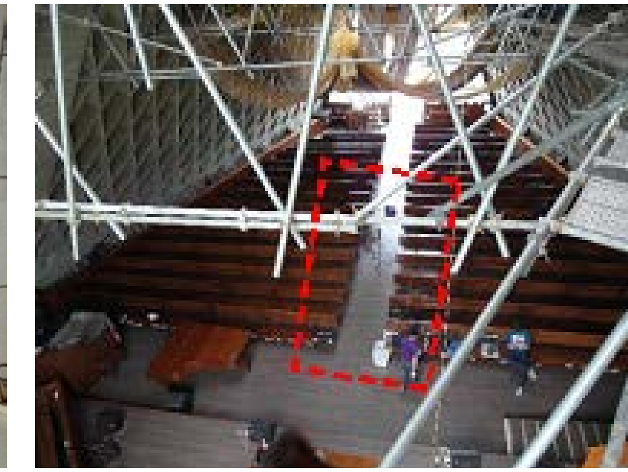
The biggest obstacle in improving ventilation is renovating the rooftop of the chapel. After investigating the present condition, the current skylight, which has been changed from the original blinds to flat skylight, was found to be the main hindrance to the thermal environment of the chapel. In 1993, the flat skylight was sealed to solve leakage problem, which decreases the interior natural ventilation and heat load dissipation of the chapel.

Additional factors obstructing natural ventilation were also found (Fig.6.8):

1. Lower blinds at the west and east sides of the chapel are blocked by inner glass windows, which decrease valid openings and deter ventilation efficiency.
2. Interior objects, such as low shelves and the backrests of the pews block the ventilation route and interfere airflow.

6.8 Factors interfering natural ventilation

6.9 Noise from the air-conditioning engine



6.10 Sultry aisle seats

6.11 Rusted blinds caused by the vapored water from the cooling tower

4. HVAC system

1. Noise from the engines of the air-conditioners in the basement influences people at the pulpit and the front seats. (Fig.6.9)
2. Users indicate that air at the aisle seats is sultry and heated. (Fig.6.10)
3. Water vapor coming from the cooling tower rusted the window frames and the blinds. (Fig.6.11)
4. When the crowd within the chapel gets overloaded, the air quality drops as the lack of outdoor air input sterilizes the indoor ventilation with air lingering inside the chapel for too long.

Analyses and improvement plan

1. Proposal of energy conservation through glass

he present glass used in the chapel is observed to be 8 mm Clear Float Glass whose SC value is relatively high. However, this also means its solar radiation resistance is rather insufficient. Furthermore, considering how large openings at the east and west ends of the chapel rapidly rise the indoor thermal loads, glass must be one of the highlight of indoor thermal improvement.
When selecting the glass, three major factors should be considered:

I.Shading Coefficient (SC)
Shading coefficient is a value that determines the influence of glass material to the energy consumption of a building. Essentially, it is the ratio of solar gain (due to direct sunlight) passing through a glass unit to the solar energy, which passes through 3mm Clear Float Glass. The lower SC value indicates the lower rate of thermal transmittance.

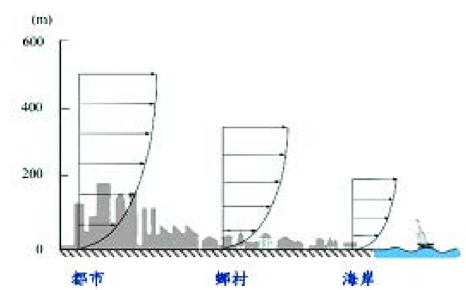
II.Reflectivity of Visual Light
The higher reflectivity of visual light indicates greater light pollution of the surroundings. To avoid light pollution and misleading reflection that induces animals bumping into the glass of the chapel, the reflectivity of visual glass should be strickily controlled.

III.Transmission of Visual Light
The sunlight is efficiently transited into indoor illumination with a higher transmission of visual light.
The plan conducting team first handed over the fragment (Fig.6.1) of the original designed glass to Research Center for Energy Technology and Strategy, National Cheng Kung University to examine and collect its various performance data (Fig.6.13). Committing to bring back the original design of the architect C. K. Chen,

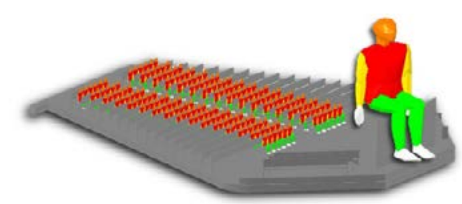
6.12 The appearance comparison of the original designed glass and clear float glass

6.13 Full viewof the equipment of Research Center for Energy Technology and Strategy

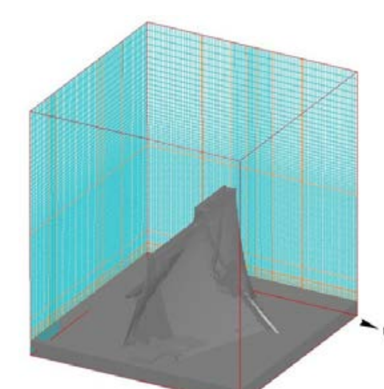
6.15 Position of the west-east oriented upper blinds



6.16 Atmospheric boundary layer diagram



6.17 The heating object model setting



6.18 Model and grids schematic diagram

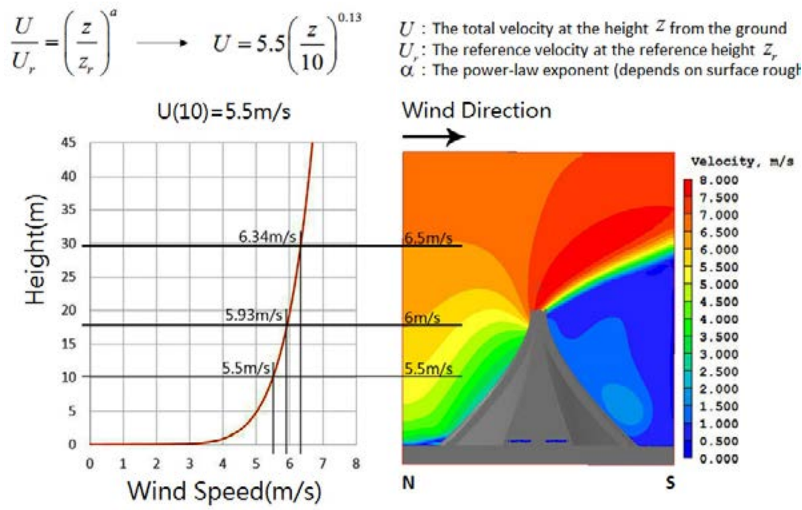
色別 Color	厚度 (mm) Thick	可見光 透過率 (%) Trans. (380nm ~ 780nm)	可見光 反射率 (%) Reflec.	紫外線透過率 (%) UV Trans. (300nm ~ 380nm)	太陽熱能 反射率 (%) Reflec.	太陽熱能 吸收率 (%) Absorb.	太陽熱能 直接透過率 (%) Direct Heat Trans. (300nm ~ 2500nm)	太陽熱能 總透過率 (%) Total Heat Trans.	U值 冬夜 (W/m²) Winter Nighttime	U值 夏日 (W/m²k) Summer Daytime	遮蔽係數 Shading Coefficient	廠商 Company
清玻璃 (現況)	8	88	8	61	7	14	79	83	5.75	5.19	0.96	台灣玻璃
東海玻璃 (原設計)	6	53.44	5.35	32.83	4.93	62.24	56.38	68	5.59	5.85	0.79	旭日(日本)
離線反射玻璃 (透明+灰膜)	6	50	8	32	7	47	46	61	5.62	5.05	0.70	台灣玻璃
色板玻璃(灰)	6	45	6	17	6	50	44	60	5.79	5.23	0.68	台灣玻璃
膠合玻璃 5mm清玻+B50+5mm清玻	10(5+5)	64.71	6.25	4.94				50			0.578	台灣節能膜
LOW-E真空玻璃	8(4+4)	49	11		28	44	28	44	0.60	0.61	0.50	台灣玻璃

6.14 Glass Data Chart

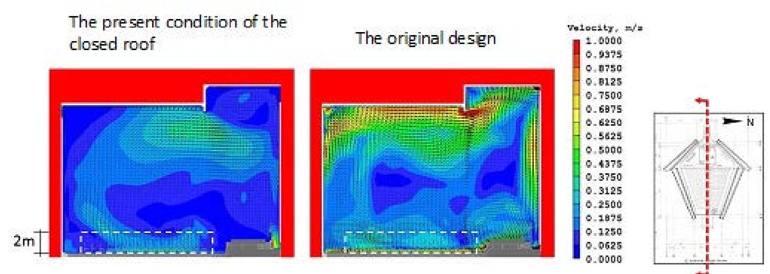
the research team also contacted the Taiwan Glass Ind. Corp. and provided the data to request products with similar transmission of visual light and better heat insulation quality. Eventually, laminated glass from Taiwan Energy Saving Film Company and LOW-E vacuum glass from Taiwan Glass Ind. Corp. were selected. Both of them obtain transmission of visual light similar to the original design; however, with a lower SC value, radiation efficiency can be obtained (Fig.6.14).

2. Natural ventilation and air flow distribution

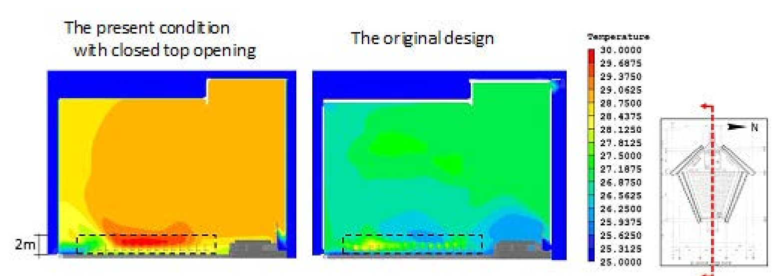
The original design was compared with the present condition of the chapel under CFD simulation. With the closed top opening, the opening blinds on the west and east ends of the chapel are the only openings remain in the chapel (Fig.6.15). Objects on the ground hinders air flow while the outside wind velocity decreases as it approaches the ground from the sky, and the roughness of the ground determines the decreasing degree of the velocity. This velocity distribution is called atmospheric boundary layer phenomenon (Fig.6.16). Simulation model was set at a model size of 40m × 40m × 45m and the amount of cell was 2700000 (Fig.6.18). The model was set at a heating density of 200 users with relatively close in seating (Fig.6.17). After studying the data from Wuqi Weather Station, the January 2015 weather data (i.e. 5.5m/s north wind at 10m height and 25℃ outside temperature) was adopted as the boundary condition setting. Then, the accuracy of the accumulated simulation setting was calculated with the equation on excel (Fig.6.19).



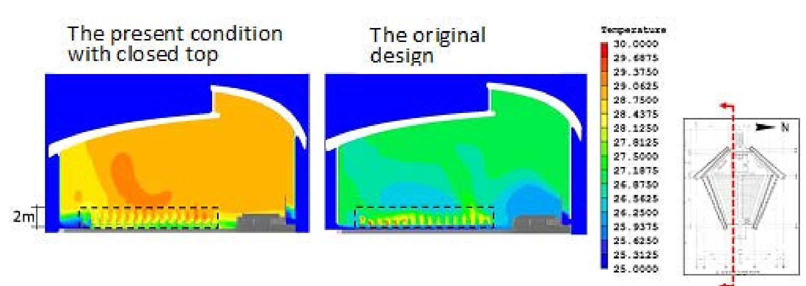
6.19 Comparison between equation of atmospheric boundary layer and simulation settings



6.20 Wind velocity comparison between the present condition and the original design (section of the lengthwise)



6.21 Temperature comparison between the present condition and the original design (section of the lengthwise)

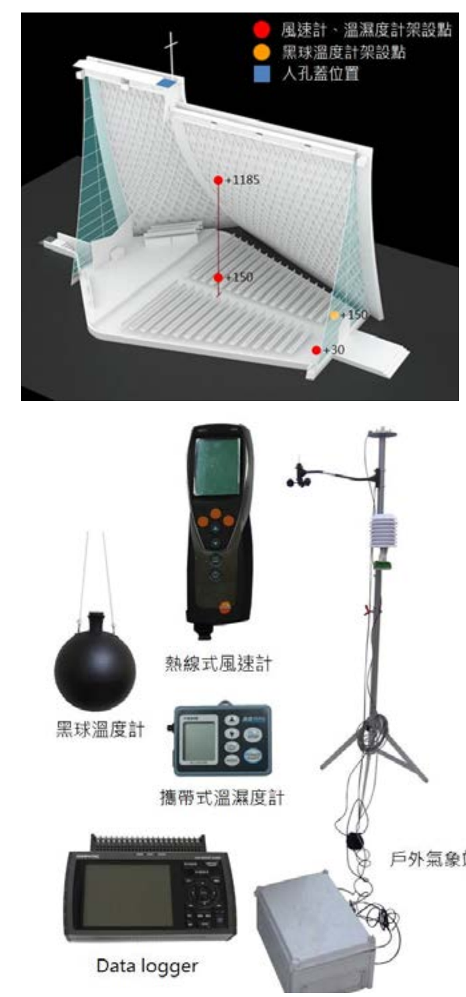


6.22 Temperature comparison between the present condition and the original design (section of the lengthwise)

Taking the height of 2m (black dash line) as the seating area for simulation, the result indicates that the thermal comfort will improve remarkably if the rooftop design can to be restored. The average interior wind velocity will increase following the drop of room temperature by 2 degrees (Fig.6.20~ Fig.6.22).

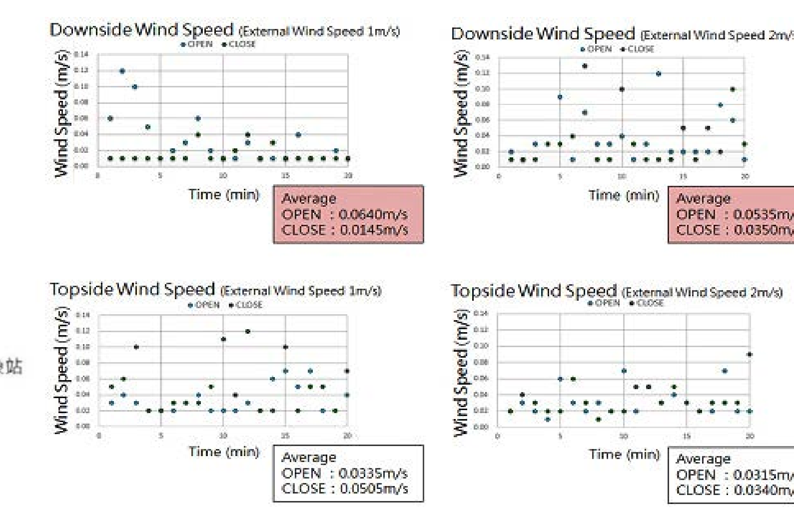
In order to confirm the effect (i.e. improvement of indoor ventilation) of the rooftop opening, the research team conducted onsite measurements in March. We set two wind velocity meters in the middle of the chapel, while one wind velocity meter and one black bulb temperature meter were placed at the entrance (Fig.6.23). Data collected during the manhole opening and closed time frame were analyzed respectively (Fig.6.24). Sampling data from the data logger was adopted from a continuous time frame of 20 minutes when the average wind velocity outdoor is similar to the indoor velocity within 10 minutes.

According to the data (Fig.6.25), even though the measurement was not collected during service hours with heating objects (users) to drive updraft, the average wind velocity with the opened manhole is still slightly higher than the hours with closed manhole. Therefore, having rooftop openings does enhance indoor natural ventilation.



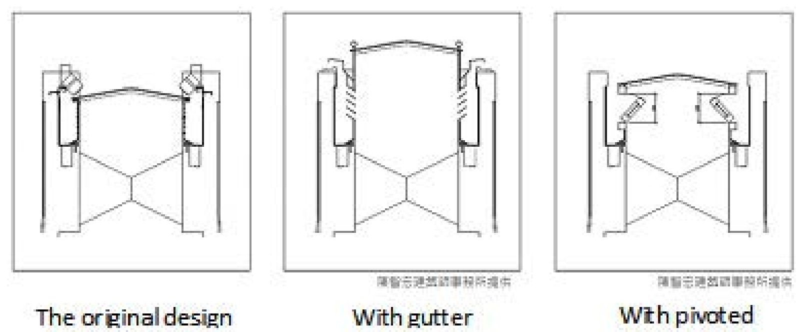
6.23 Measuring meters and locations

6.24 Manhole opening operation

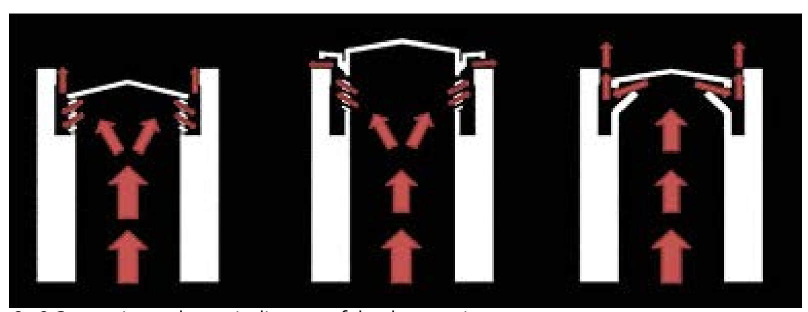


6.25 Wind Speed Measurements

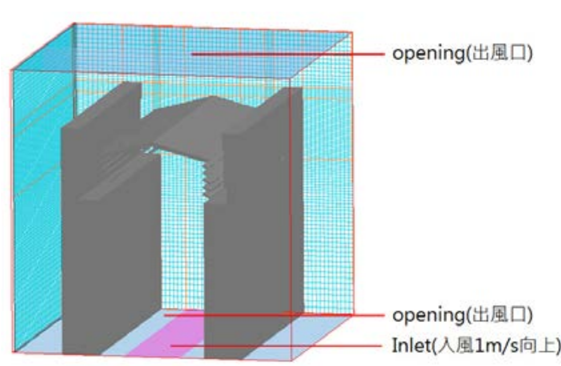
An airflow visualizing experiment was operated with a smoke producer during the onsite measurement (Fig.6.26、Fig.6.27). The smoke was released once during the manhole opening and closed time frame respectably. The measuring process was recorded and according to the video, the smoke rapidly speeded and was withdrawn when it reached the opened manhole, whereas the smoke rose gradually and drifted along the skylight when the manhole was closed.
Through simulations and measurements, having a rooftop opening is confirmed to have improved the indoor natural ventilation. Therefore, this research team proposes improving the airflow by restoring the original design (i.e. non-closed opening) and then replace the blinds of the upper opening into pivoted window to serve as the air flow conducting component for the air to flow smoothly. In the fourth meeting of the conservation project, the team cooperated with architect Zhi-hong Cheng and his associates, and asked them to provide three options of rooftop opening designs for our team to conduct CFD simulation. After conducting a thorough CFD simulation, the design, which resulted the greatest thermal comfort improvements, was single out from the three.
The three options are as the following: 1. Restore the original design by raising the rooftop and an additional gutter to solve the leakage problem. 2. Restore the



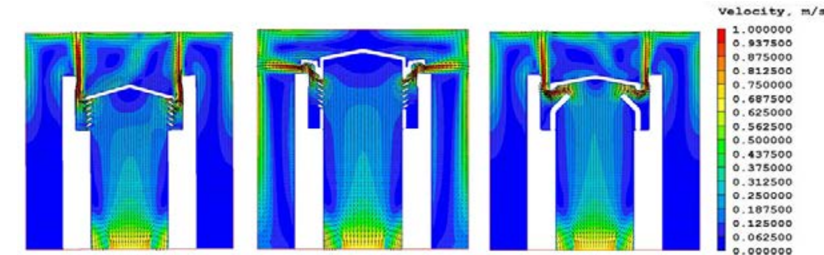

6.26 Airflow visualizing experiment

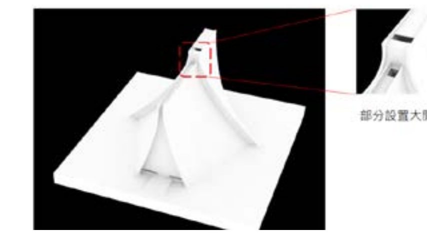

6.28 Comparison schematic diagram of the three options

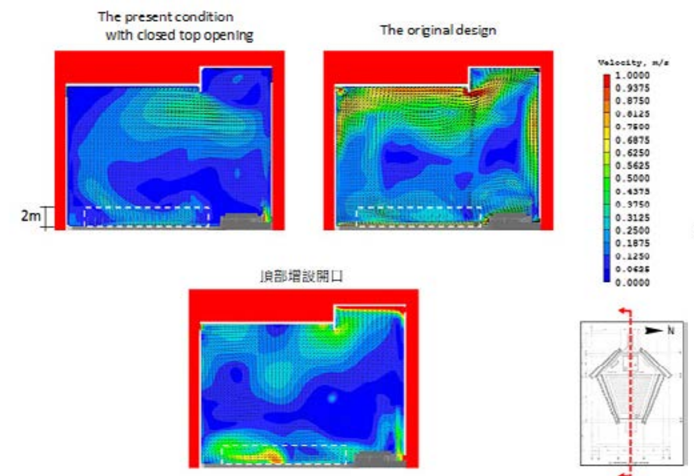

6.27 Smoke producer



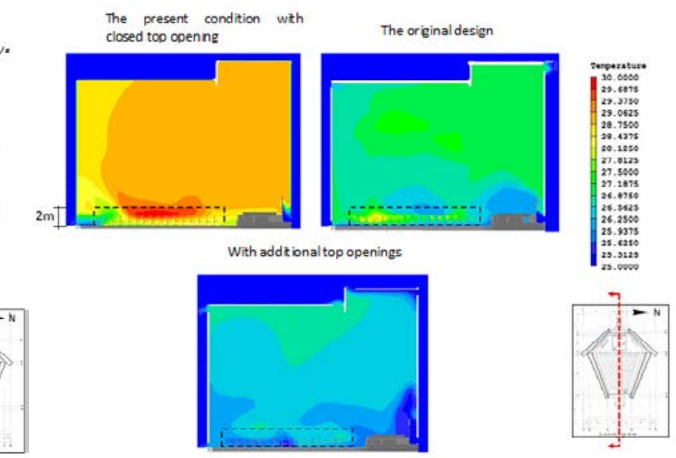
6.29 Model and grids schematic diagram


6.30 Wind velocity comparison of the three options

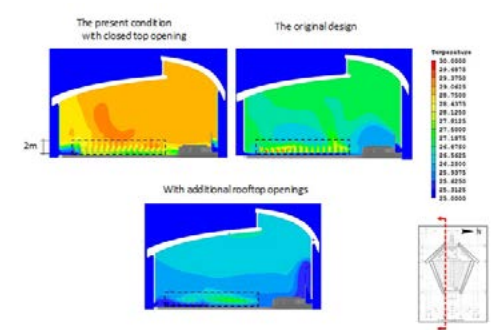

6.31 Design schematic diagram of the additional opening at the top



6.32 Wind velocity comparison of the present condition, the original design, and the design with additional rooftop openings (longitudinal section)



6.33 Temperature comparison between the present condition, the original design, and the design with additional rooftop openings (longitudinal section)


6.34 Temperature comparison between the present condition, the original design, and the design with additional rooftop openings. (longitudinal section)

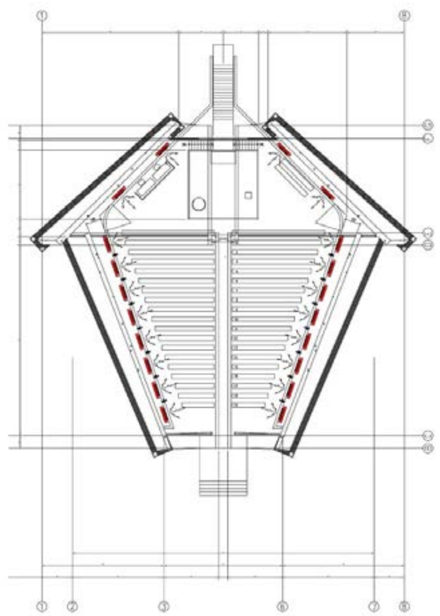
original design by replacing the blinds with pivoted windows. 3. Add other openings on the rooftop with a remote control to open and close the opening (Fig.6.28).
There are more constructional details with the first two options provided by Zhi-hong Cheng architect（陳智宏建築師） and his associates. It is difficult to detect tiny objects under a large scale model. Therefore, the model used for simulation was reduced to a 2m × 2m × 2m model with 343000 cells (Fig.6.29), with the intake air velocity set at 1m/s. This model was adopted to simulate the ventilation performance of the original design, the gutter proposal and the pivoted windows suggestion.
The simulation result indicates that these designs are rather similar in effect. Hence, the team took the equation for ventilation (i.e. average wind velocity of the opening × size of the opening) to compare the ventilation performance. The ventilation performance of the original design: gutter: pivoted window design is 1: 0.3: 0.94, whereby the team acknowledges that the ventilation effect of the original design is better than the other two options (Fig.6.30).
As for the option of additional openings (Fig.6.31), the former simulation model was applied (Fig.6.18). After comparing with the original design and observing the seating area (black dashed zone), the simulation result indicates the similarity in wind velocity between having additional openings and the original design, with an improvement on heat load dissipation, which reduces the temperature by 1 degree. As a result, addition al openings design is the best solution for enhancing indoor thermal comfort comparing with other given propositions (Fig.6.32、Fig.6.33、Fig.6.34).

3. Studies for HVAC system design

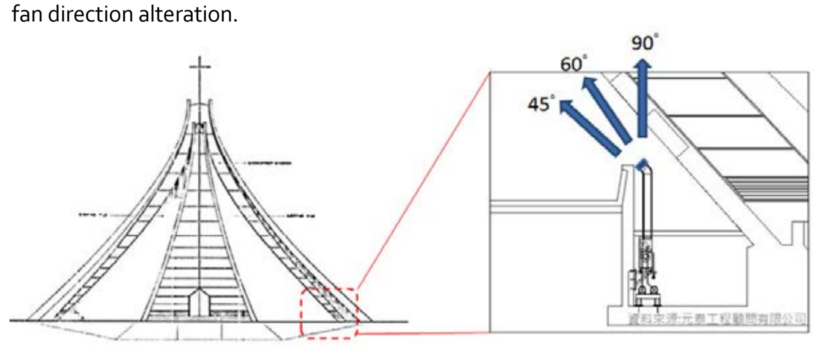
In order to resolve the sultriness brought forward by crowds of users, this research team cooperated with Yi-tai Tsai Air-conditioning Engineering Associates, and requested a HVAC system configuration plan for simulation analysis (Fig.6.35). By adjusting the angle of fan direction, the air-conditioning effect was expected to cool the chapel evenly and resolve the problem of thermal discomfort for some users.

Yi-tai Tsai Air conditioning Engineering Associates (蔡逸泰空調技師團隊) provided a HVAC simulation setting with a wind velocity of 1.25m/s, a temperature setting of 20℃ , and fan angles of 45°, 60°, 90°(Fig.6.36), while other setting remained the same (Fig.6.18). The simulation result highlighted the temperature differences of the seating area within the black dash zone. The thermal performance of 90° fan angle was better than the 60° fan breeze, and the 60° was better than the 45°. The temperature differences between the 90° breeze and 60° breeze was about 1.5℃ . The close examination indicates that the 90° fan direction coincides the hyperboloid structure of the chapel. The airflow bounced to the central seating area after hitting the shell walls, whereas the breeze of the 45° fan direction followed the principle of cold air drops, and had the breeze dropped below the seating area, where contributed less to thermal comfort (Fig.6.37、Fig.6.38、Fig.6.39).

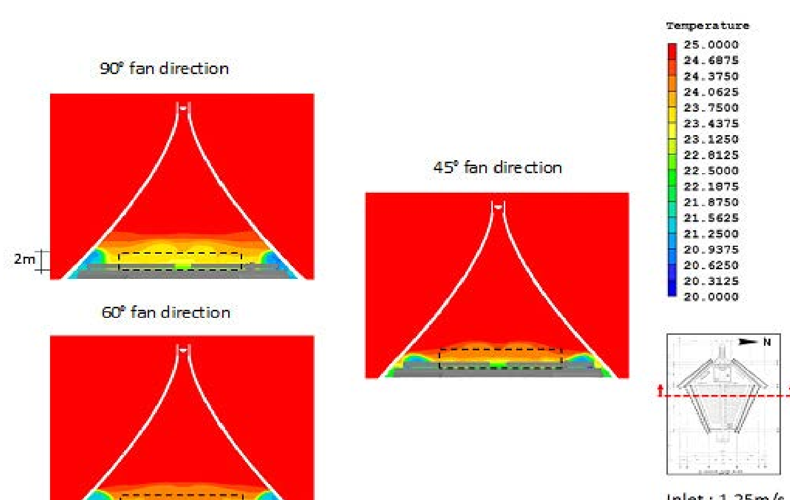
Failing to have an eminent simulation result on the first simulation, the team doubled the wind velocity from 1.25m/s to 2.5m/s and operated another simulation (Fig.6.40、Fig.6.41、Fig.6.42). This simulation indicates a more evident effect of fan direction alteration.



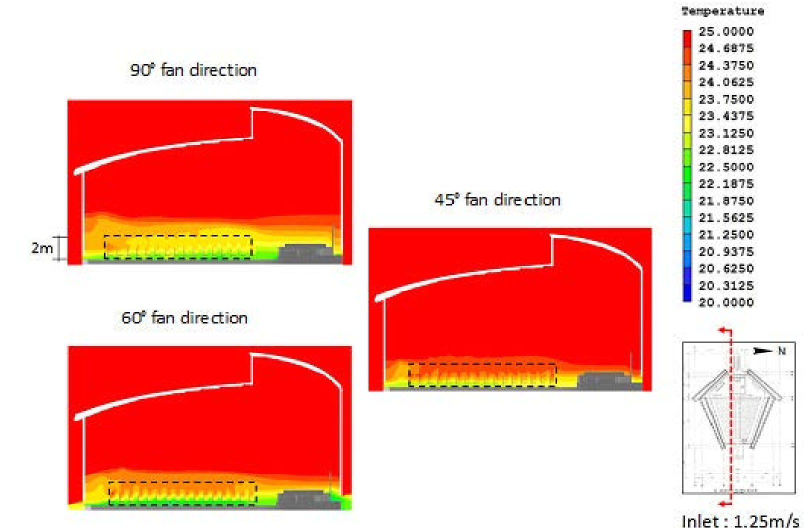
6.35 Positions of the air-conditioner indoor unit



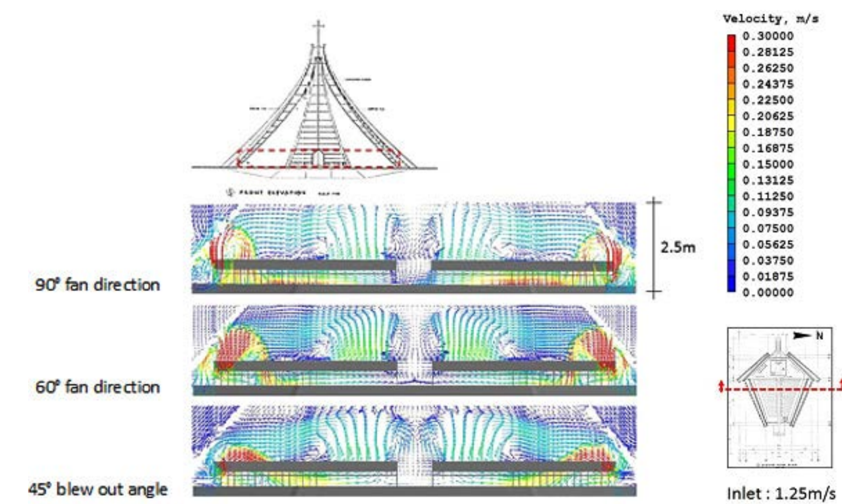
6.36 Indoor air-conditioner setting



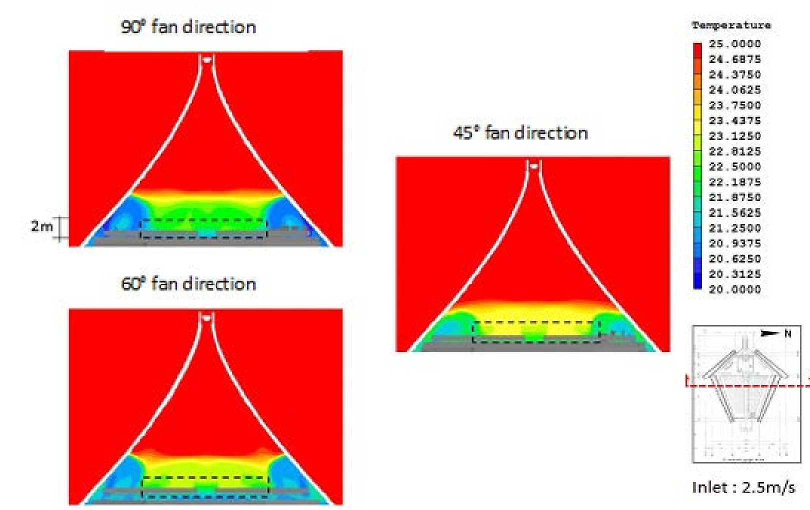
6.37 Temperature comparison between the three fan directions (cross section)



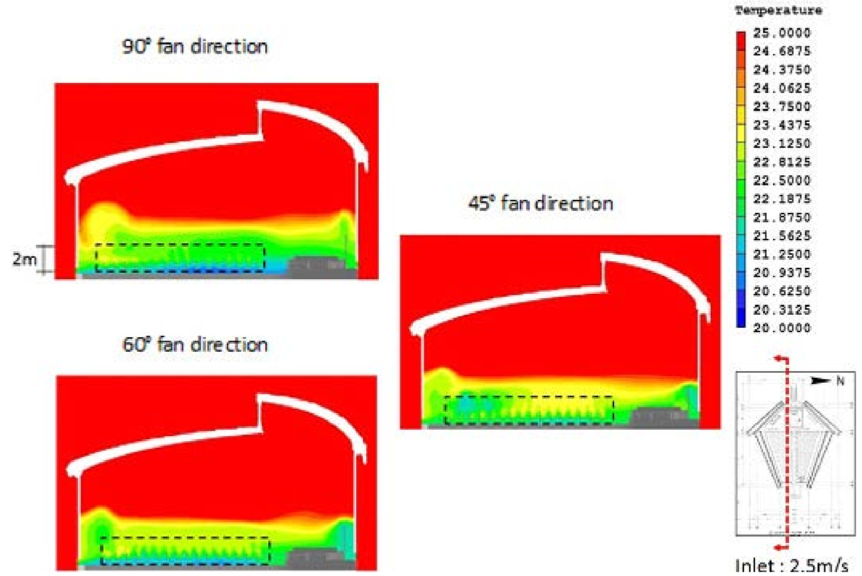
6.38 Temperature comparison between the three fan angles (longitudinal section)



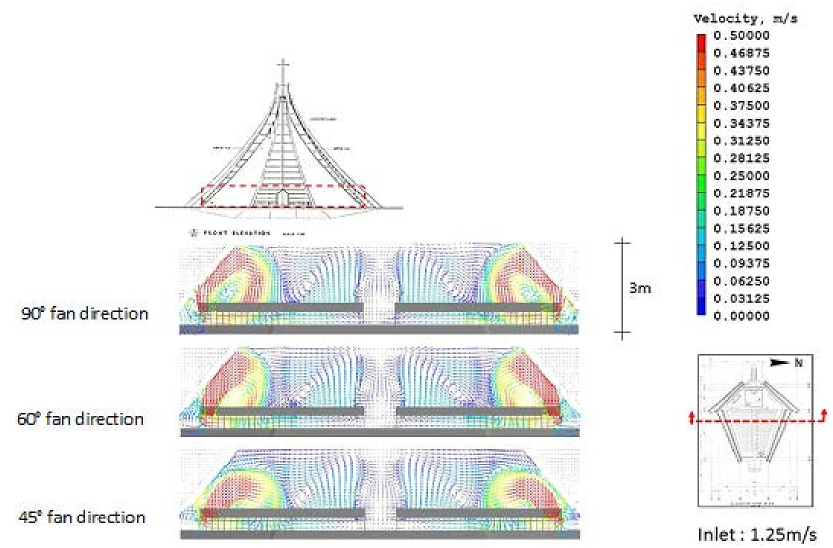
6.39 Wind velocity comparison between the three fan directions(cross section, seating area)



6.40 (The second simulation)Temperature comparison between the three fan directions (cross section)



6.41 (The second simulation) Temperature comparison of the three fan directions (longitudinal section)



6.42 (the second simulation)
Wind velocity comparison between the three blew out angle (cross section, seating area)

Conclusion

1. Replacement of glass on the west and east openings

The choice of glass involves more than insulation efficiency. The interior lighting and ecological impact are also important factors to be considered. The sacredness of the chapel is the most essential character, which is indivisible with the architectural lighting within the chapel. Therefore, as fulfilling the energy saving purpose, the historical factor, which attracts visitors, should also be take into equivalent consideration.

2. Natural ventilation improvement

Base on the above simulation and onsite measurement results, having rooftop openings proves to enhance the indoor natural ventilation performance. Moreover, having additional rooftop openings would be far more efficient than modifying the original design. Eventually, on the premise of keeping the appearance of the chapel, issues such as leakage and thermal comfort improvement, which need to be resolved under renovation budget, are the task to be put into consideration.

3. HVAC system design

According to the simulation result, with the air-conditioning designs provided by Yi-tai Tsai Air-conditioning Engineering Associates, the 90° fan direction is most efficient in delivering cool air to the central seat area, whereas the performances of the 60° and 45° gradually decline as the fan angles decrease accordingly.

7. LUCE Chapel HVAC System Renovation Study

Yuan Tai Consulting Engineers, Co. Ltd.
2015. 09.07

1. Existing HVAC System Status Description

The existing air conditioning (AC) system of the Luce Chapel was installed at the basement three years ago. Two water cooled air handlers which each carries a capacity of 20 RT/72kw were placed at the corners of the basement (Fig.7.1) with two sets of outdoor water cooling towers providing condenser water to the air conditioners in the basement(Fig.7.2). Each packaged air handler is connected with supply air duct (set in the indentations at the sides of the seating area) to deliver conditioned air to the first floor. Each ductwork system has 11 air grilles, set at 60 degree in angle, to supply cold air to the nave and chancel (Fig.7.3). The return air is drawn back to the water cooled air handlers in the basement through the stairways behind the chancel to complete the air conditioning cycle.

By surveying different seating areas locationed at the first floor, the air was found to have fairly even distribution among the first floor seating area. Temperature variations among each location were also limited. The minor stagnant air zone only appeared at the area around the central aisle. However, the operating noise of package air handlers was around 73 dBA (measured at the basement), which then transmitted via the stairways to the chancel. The rumbling noise was also audible in the first 3 to 4 rows of the seating area. For this reason, many audience had complained about the AC noise for affecting the speech intelligibility of lectures or sermons. Therefore, reducing the operating noise has become a major concern for renovating the chapel's AC system.

Another drawback of the existing air-conditioning system is the problems caused by the cooling towers outside the basement. The air intake louvers behind the first floor pulpit have been sealed to prevent polluted air and fan noises from the cooling towers. Furthermore, the splashing water droplets dripping out of the cooling towers has caused significant corrosion on the metal frame of the first floor glass window (Fig.7.4)

Fig.7.1 Water cooled air handlers at the basement


Fig.7.2 Outdoor water cooling towers outside the basement

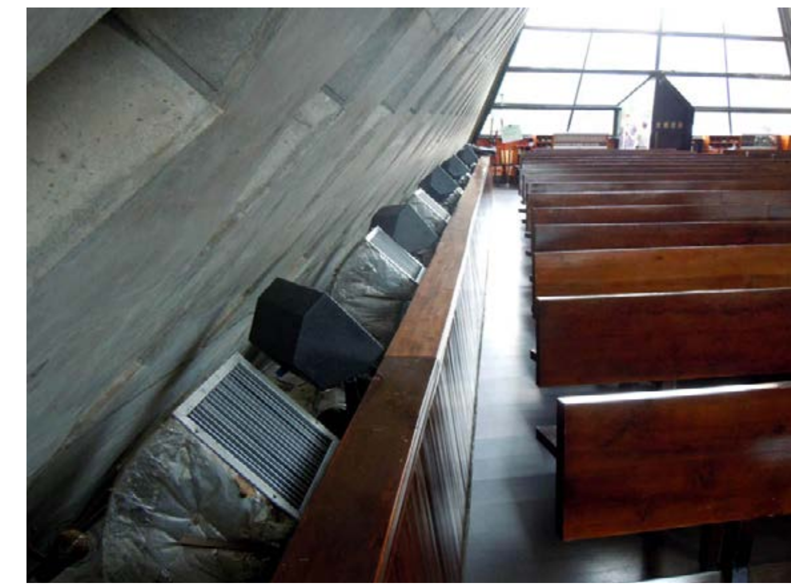


Fig.7.3 The ductwork system besides the seating area

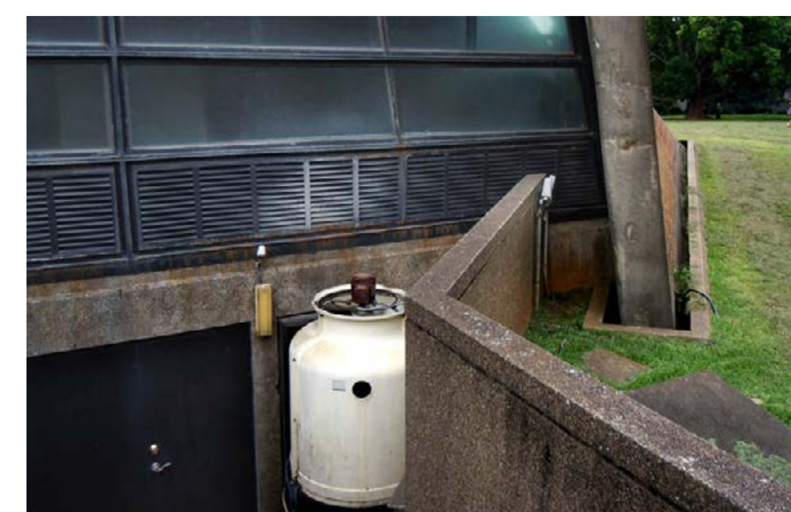


Fig.7.4 Corrosion on the metal frame of the first floor glass window

2. Renovation Proposal

To improve the deficiencies of the existing AC system, with the awareness of the space constraints at the Luce Chapel, this research team proposes two solutions. Solution A uses the "Air-cooled Variable Refrigerant Volume (VRF) chiller + VRF indoor unit + Direct Expansion (DX) pre-cooled outside air handler," and Solution B offers "Air-cooled Water Chiller Unit + Straight Water Chiller Air-condition Box" as the solutions for air conditioning renovation. The choice of air conditioners in both solutions were made according to the air-condition loading anaylses.

AC system load and Air volume:
Recommended by the research of Associate Professor Y.S. Tsay for this project, the SC (shading coefficient) value of replacing windows is estimated to be 0.58. Associated with intake outdoor air volume, internal load of audience and lighting, and the envelope volumes and properties; the AC load of Luce Chapel was calculated by using TRACE 700 software developed by TRANE. The calculation result of the chapel's AC system load was 137.4 kw(39 USRT), and the supply AC flowrate required was 4,530 L/S for the seating zone(including the pulpit). (see Attachment- 1)

Introducing outdoor air volume:
Referring to American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 62.1 ventilation standard, the outside air volume the Luce Chapel needs is about 1,300 L/S (2.5 L/S per person+ 0.3 L/S per m2 floor area). The proposed outdoor air intake system should introduce fresh air through the west side louvers in thebasement (see Attachment- 2).

The contents of these two solutions are as the following.

Solution A:
"Air-cooled Variable Refrigerant Volume (VRF) chiller + VRF indoor unit + Direct Expansion (DX) pre-cooled outside air handler"
This alternative adopts two sets of highly efficient air-cooled VRF chiller units (19 RT/68 kw each). The units shall be installed in the parking area away from the back of Luce chapel. The refrigerant pipes from the VRF chillers shall go through a new trench (under the lawn behind the chapel), and extend to the chapel basement, first connecting to the two DX pre-cooled outside air handlers (same locations as existing water-cooled air handlers), then further extend to the VRF indoor units in the indentations at both sides of first floor seating area. These VRF indoor units (provisionally 20 units total; 10 units per side), each is fitted with a refrigerant regulating valve, a supply air plenum and a grille. They will provide cooled air to condition the nave and chancel at the first floor. The operating noise is predicted to be around 40 dBA to 45 dBA, which is fairly low comparing with general AC machines.

1. Supply air projection angle:
Referring to the CFD simulation results of Associate Professor Y.S. Tsay for this project, the 90 degree supply air projection angle among at the congregation seating area will generate the best air distribution result for audience at the pews. However, considering the multifunctional usage of Luce Chapel, these supply air grilles should have an angle adjustable feature that is capable of adjusting air throw angles from 45 degree to 90 degree. The supply air projection angle is adviced to be first set at 90° in advance when the installation is completed. (see Attachment – A1)

2. Introducing outdoor air volume:
Fresh air will first be filtered, cooled and dehumidified by the DX pre-cooled outside air handlers. Then, the air handlers will deliver the conditioned outdoor air via the small size ducts installed in the indentations at the sides of the first floor seating area. In the end, the outdoor air will be pushed via small branched ducts and projected into the nave and the chancel. By supplying sufficient fresh outdoor air, this new AC system will have a much better ventilation performance comparing to the existing system. (see Attachment –A2~A3)

3. System operation efficiency:
This AC renovation system is planned to adopt the most advanced DC driven variable frequency type compressors. The running frequency and refrigerant flow volume of the compressors can be automatically adjusted according to various loads of the air conditioning system for the best efficiency. In addition, the supply/ return air volume of DX type indoor units can be manually or automatically adjusted. The number of running indoor units also can be chosen according to the user demand in the chapel. All these features can enhance the overall efficiency of the air conditioning system. (see Attachment – A4)

4. Noise:
Considering the AC system operating noise control, the VRF outdoor unit (containing compressors) should to be located in the parking zone that is about 40m away from the west side of chapel (see Attachment – A5). There are two behefits for this practice. First, the noise of the outdoor units is about 60 dBA. The impact of the units will be reduced with the noise further away from the beautiful and tranquil green surroundings of the chapel. Second, the outdoor unit in the parking area can be concealed with decorated grilles or fences, which shall easily fit into the overall landscape design. The single VRF indoor unit of this AC system has high/moderate/low speed operating noise at 39/36/32 dBA respectively. And if all the indoor units are occupied, the integrated noise might fall between 41 to 45 dBA, which is equivalent to NC-35 to NC-40 even at moderate speed. Although this level of noise does not meet the NC-30 request given by the acoustic consultant, it should still improve the original operating noise of NC-50 by leaps and bounds.

5. Pros/Cons:
First, the proposed AC system does not need cooling towers. The issue of first floor metal window frame corrosion caused by the splashing water droplets from the cooling tower will be eliminated. Second, the 20 small VRF indoor units installed in the indentations at the sides of the nave will be able to be set in a distance, and release some space (compared to the large air ducts of the existing system). The released space can be used for auxiliary lighting installation for the illumination of the nave during night events. This is the additional advantages of this proposed AC system. However, the drawback is that the VRF indoor units need regular cleaning and maintenance (quarterly and annual maintenance). Due to the width restrains of the indentations at both sides of the nave, it requires the maintenance staff to climb over the fence in/out of the indentations for maintaining the VRF indoor units whenever the maintenance or cleaning work is needed. Moreover, this type of VRF air-condition units are imports from Japan and Korea; therefore the cost will be 20 to 30% higher than Solution B.

Solution B:
"Air-cooled Water Chiller Unit + Straight Water Chiller Air-condition Box"
This solution introduces one set of highly efficient air-cooled VRF chiller units (40 RT/140 kw). The units shall be installed in the parking area away from the back of Luce chapel. The refrigerant pipes from the VRF chillers shall also go through a new trench (under the lawn behind the chapel), and extend to the chapel basement, first connecting to two Straight Water Chiller Air-condition units (each carries a cooling efficiency of 70 kw), then each unit shall further extend to the VRF indoor units in the indentations at both sides of first floor seating area through an air supply duct respectively. Each air supply duct distributes 10 supply air plenums with grilles bringing cool air to the nave and chancel. These two straight air-condition units can be set to low operating noise, which can reduce the current noise to 60~63 dBA. Furthermore, with the units positioning at the basement, adding supplimentary sound arresters will be able to decrease the noise to 38~43 dBA (depending on the operating air volume).

1. Supply air projection angle:
Same as Solution A, this alternative also refers to the CFD simulation results of Associate Professor Y.S. Tsay. The 90 degree supply air projection angle among at the congregation seating area will generate the best air distribution result for audience at the pews. However, considering the lighting design for the illumination of the lattice beam, the main air supply duct shall be installed at the lower part of the indentation, and the top of the minor pipes shall not be higher than the light projections on the sides. Moreover, considering the multifunctional usage of Luce Chapel, the supply air grilles shall also have an angle adjustable feature that is capable of adjusting air throw angles from 60 degree to 90 degree (due to the low position of the supply air grille, the turning angle will be limited to 60 degree). The supply air projection angle is also adviced to be first set at 90° in advance when the installation is completed. (see Attachment – B1)

2. Introducing outdoor air volume:
Fresh air will enter the chapel through a new shutter and wall fan at the basement. The air will first join the first floor return air at the stairway, be filtered, cooled and dehumidified by the Straight Air-condition unit, then delivered to the indentations at the sides of the seating area through large air supply ducts. Small air pipe and air supply grille will then fill the nave and chancel with cool air. The first floor return air will flow through the stairway behind the pulpit and then back to the air-condition units to complete the cycle. This solution shall ensure the sufficiency of fresh air in the air-condition system, and improve the current ventilation deficiency (see Attachment B2~B3).

3. System operation efficiency:
The size of this AC system is rather small. This research proposes the application of multiple small hermetic scroll compressors. The number of units and the air volume of the main compressor can be adjusted according to the variation of air-conditioner load through central control. This shall maximize the operating efficiency. Moreover, the striaght air-condition unit should be a Variable Air Volume unit, which allows manual or automatic air volume adjustment of supply/return air (according to the temperature of return air). This shall increase the overall operating efficiency of the AC system. However, this solution does not provide sectional operation, once the unit is turn on, the entire system will be involved in operation (see Attachment B4).

4. Noise:
The outdoor unit (containing compressors) shall also be located in the parking zone that is about 40m away from the west side of chapel (see Attachment – B5). There are two behefits for this practice. First, the noise of the outdoor units is about 70 dBA. Having the units further away from the beautiful and tranquil greens of the chapel will reduced noise. Second, the outdoor unit in the parking area can be concealed with decorated grilles or fences, which shall easily fit into the overall landscape design. The striaght air-condition unit proposed in this solution has a higher operating noise around 60 dBA, therefore, it will be essential to install noise barrier around the units at the basement, apply acoustic absorbing material on the ceiling and walls, and utilizes the space at the basement as a buffer to absorb/seclude noise. This will require the assistant of an acoustic consultant, and the indoor noise at the first floor shall be decreased to 38~40 dBA. This is a great improvement comparing with the current operating noise, which is more than 50dBA.

5. Pros and Cons:
This solution doesn't require cooling towers. Therefore corrosion at the metal frame of the first floor window will no longer be an issue. In addition, although this solution requires the addoption of medium/large air ducts at the sides of the first floor indentations, with a careful construction, the supplimentary lighting equipment at the indentation will not be effected, and the lighting effect at the seating area will remain the same way the designer had planned. The biggest differences between Solution B and A is that the units will all be outdoor or behind the basement, and the relative devices are few, which shall drastically reduce the workload of miantenance. Furthermore, these units are all made in Taiwan; therefore it will be cheaper for purchase and future repair. Nevertheless, the flaw is that the system cannot function sectionally. Once it is turn on, the whole system will be involved in operation, which is similar to the current operating method. The air ducts of this solution are also larger than the ones used in Solution A (the biggest duct comes in at 85cm*55cm, including the thickness of thermal retaining material). Moreover, parts of the space in the basement will be given up when it is used as a buffer for noise deduction. Applying acoustic absorbing materials at walls and ceiling will also introduce additional construction expense.

Attachment - A

空調負荷分析_5pm/July

Room Checksums
By Trane

Room - 003_8in LW Conc

COOLING COIL PEAK — Peaked at Time: Mo/Hr: 7 / 17; Outside Air: OADB/WB/HR: 33 / 26 / 18
CLG SPACE PEAK — Mo/Hr: 7 / 17; OADB: 33

	Space Sens. + Lat. kW	Plenum Sens. + Lat kW	Net Total kW	Percent Of Total (%)	Space Sensible kW	Percent Of Total (%)
Envelope Loads						
Skylite Solar	3.01	0.00	3.01	2	3.01	5
Skylite Cond	0.60	0.00	0.60	0	0.60	1
Roof Cond	0.00	0.00	0.00	0	0.00	0
Glass Solar	20.87	0.00	20.87	16	20.87	31
Glass Cond	7.95	0.00	7.95	6	7.95	12
Wall Cond	12.80	0.00	12.80	10	12.80	19
Partition	0.00		0.00	0	0.00	0
Exposed Floor	0.00		0.00	0	0.00	0
Infiltration	0.00		0.00	0	0.00	0
Sub Total ==>	45.23	0.00	45.23	34	45.23	68
Internal Loads						
Lights	4.75	0.00	4.75	4	4.75	7
People	35.14		35.14	26	16.83	25
Misc	0.00	0.00	0.00	0	0.00	0
Sub Total ==>	39.89	0.00	39.89	30	21.58	32
Ceiling Load	0.00	0.00	0.00	0	0.00	0
Ventilation Load	0.00	0.00	48.76	36	0.00	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0.00		0.00	0	0.00	0
Exhaust Heat		0.00	0.00	0		
Sup. Fan Heat			0.00	0		
Ret. Fan Heat		0.00	0.00	0		
Duct Heat Pkup		0.00	0.00	0		
Reheat at Design			0.00	0		
Grand Total ==>	85.12	0.00	133.88	100.00	66.81	100.00

HEATING COIL PEAK — Mo/Hr: Heating Design; OADB: 9

	Space Peak Space Sens kW	Coil Peak Tot Sens kW	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0.00	0.00	0
Skylite Cond	-1.17	-1.17	3
Roof Cond	0.00	0.00	0
Glass Solar	0.00	0.00	0
Glass Cond	-13.36	-13.36	31
Wall Cond	-10.22	-10.22	24
Partition	0.00	0.00	0
Exposed Floor	0.00	0.00	0
Infiltration	0.00	0.00	0
Sub Total ==>	-24.75	-24.75	57
Internal Loads			
Lights	0.00	0.00	0
People	0.00	0.00	0
Misc	0.00	0.00	0
Sub Total ==>	0.00	0.00	0
Ceiling Load	0.00	0	0
Ventilation Load	0.00	-18.61	43
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	0.00	0.00	0
Exhaust Heat		0.00	0
OA Preheat Diff.		0.00	0
RA Preheat Diff.		0.00	0
Additional Reheat		0.00	0
System Plenum Heat		0.00	0
Grand Total ==>	-24.75	-43.36	100.00

TEMPERATURES

	Cooling	Heating
SADB	11.4	25.7
Plenum	24.0	21.0
Return	24.0	21.0
Ret/OA	26.6	17.5
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Vent	1,301	1,301
Infil	0	0
Supply	4,284	4,284
MinStop/Rh	0	0
Return	2,984	2,984
Exhaust	0	0
Rm Exh	1,301	1,301
Auxil	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	30.4	30.4
lps/m2	10.82	10.82
Lps/kW	31.99	
m2/kW	2.96	
W/m2	337.92	-109.46
No. People	500	

COOLING COIL SELECTION

	Total Capacity kW	Sens Cap. kW	Coil Airflow L/s	Enter DB C	Enter WB C	Enter HR g/kg	Leave DB C	Leave WB C	Leave HR g/kg
Main Clg	133.87	80.44	4,284	26.6	20.0	12.2	11.4	10.9	8.1
Aux Clg	0.00	0.00	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.00	0.00	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	133.87								

AREAS

	Gross Total	Glass m2	Glass (%)
Floor	396		
Part	0		
ExFlr	0		
Roof	16	16	100
Wall	1,430	185	13

HEATING COIL SELECTION

	Capacity kW	Coil Airflow L/s	Ent C	Lvg C
Main Htg	-43.4	4,284	17.5	25.7
Aux Htg	0.0	0	0.0	0.0
Preheat	0.0	0	0.0	0.0
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-43.4			

Project Name:
Dataset Name: C:\CDS\TRACE700\Projects\10320_church_V2.trc

TRACE® 700 v6.1.2 calculated at 10:26 AM on 05/26/2015
Alternative - 1 Room Checksums report Page 2 of 2

空調負荷分析_8pm/July

Room Checksums
By Trane

Room - 003_8in LW Conc

COOLING COIL PEAK — Peaked at Time: Mo/Hr: 7 / 20; Outside Air: OADB/WB/HR: 29 / 25 / 18
CLG SPACE PEAK — Mo/Hr: 7 / 20; OADB: 29

	Space Sens. + Lat. kW	Plenum Sens. + Lat kW	Net Total kW	Percent Of Total (%)	Space Sensible kW	Percent Of Total (%)
Envelope Loads						
Skylite Solar	1.49	0.00	1.49	1	1.49	2
Skylite Cond	0.33	0.00	0.33	0	0.33	0
Roof Cond	0.00	0.00	0.00	0	0.00	0
Glass Solar	11.92	0.00	11.92	9	11.92	18
Glass Cond	4.81	0.00	4.81	3	4.81	7
Wall Cond	16.49	0.00	16.49	12	16.49	25
Partition	0.00		0.00	0	0.00	0
Exposed Floor	0.00		0.00	0	0.00	0
Infiltration	0.00		0.00	0	0.00	0
Sub Total ==>	35.04	0.00	35.04	25	35.04	52
Internal Loads						
Lights	7.15	0.00	7.15	5	7.15	11
People	61.55		61.55	45	24.92	37
Misc	0.00	0.00	0.00	0	0.00	0
Sub Total ==>	68.70	0.00	68.70	50	32.07	48
Ceiling Load	0.00	0.00	0.00	0	0.00	0
Ventilation Load	0.00	0.00	33.69	25	0.00	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0.00		0.00	0	0.00	0
Exhaust Heat		0.00	0.00	0		
Sup. Fan Heat			0.00	0		
Ret. Fan Heat		0.00	0.00	0		
Duct Heat Pkup		0.00	0.00	0		
Reheat at Design			0.00	0		
Grand Total ==>	103.74	0.00	137.43	100.00	67.11	100.00

HEATING COIL PEAK — Mo/Hr: Heating Design; OADB: 9

	Space Peak Space Sens kW	Coil Peak Tot Sens kW	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0.00	0.00	0
Skylite Cond	-1.17	-1.17	3
Roof Cond	0.00	0.00	0
Glass Solar	0.00	0.00	0
Glass Cond	-13.36	-13.36	31
Wall Cond	-10.22	-10.22	24
Partition	0.00	0.00	0
Exposed Floor	0.00	0.00	0
Infiltration	0.00	0.00	0
Sub Total ==>	-24.75	-24.75	57
Internal Loads			
Lights	0.00	0.00	0
People	0.00	0.00	0
Misc	0.00	0.00	0
Sub Total ==>	0.00	0.00	0
Ceiling Load	0.00	0	0
Ventilation Load	0.00	-18.61	43
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	0.00	0.00	0
Exhaust Heat		0.00	0
OA Preheat Diff.		0.00	0
RA Preheat Diff.		0.00	0
Additional Reheat		0.00	0
System Plenum Heat		0.00	0
Grand Total ==>	-24.75	-43.36	100.00

TEMPERATURES

	Cooling	Heating
SADB	12.0	25.4
Plenum	24.0	21.0
Return	24.0	21.0
Ret/OA	25.6	17.7
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Vent	1,301	1,301
Infil	0	0
Supply	4,534	4,534
MinStop/Rh	0	0
Return	3,233	3,233
Exhaust	0	0
Rm Exh	1,301	1,301
Auxil	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	28.7	28.7
lps/m2	11.45	11.45
Lps/kW	32.98	
m2/kW	2.88	
W/m2	346.87	-109.46
No. People	500	

COOLING COIL SELECTION

	Total Capacity kW	Sens Cap. kW	Coil Airflow L/s	Enter DB C	Enter WB C	Enter HR g/kg	Leave DB C	Leave WB C	Leave HR g/kg
Main Clg	137.42	75.91	4,534	25.6	20.5	13.2	12.0	11.9	8.8
Aux Clg	0.00	0.00	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.00	0.00	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	137.42								

AREAS

	Gross Total	Glass m2	Glass (%)
Floor	396		
Part	0		
ExFlr	0		
Roof	16	16	100
Wall	1,430	185	13

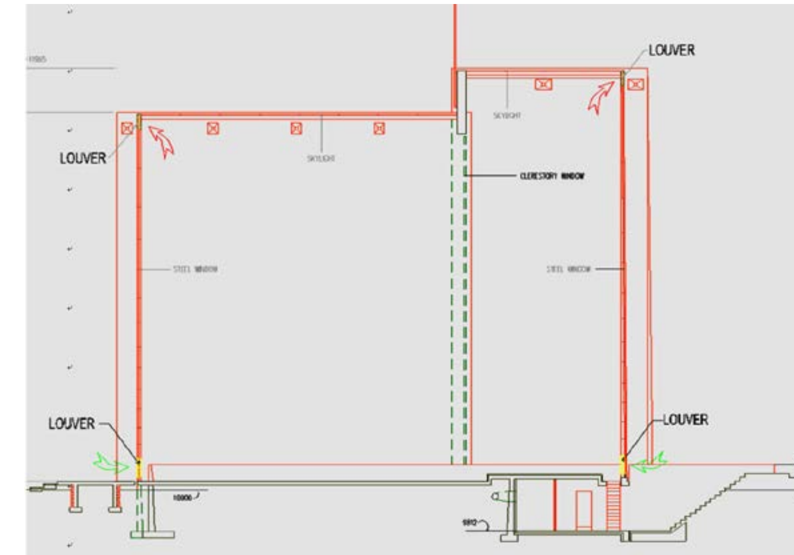
HEATING COIL SELECTION

	Capacity kW	Coil Airflow L/s	Ent C	Lvg C
Main Htg	-43.4	4,534	17.7	25.4
Aux Htg	0.0	0	0.0	0.0
Preheat	0.0	0	0.0	0.0
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-43.4			

Project Name:
Dataset Name: C:\CDS\TRACE700\Projects\10320_church_V2.trc

TRACE® 700 v6.1.2 calculated at 10:41 AM on 05/26/2015
Alternative - 1 Room Checksums report Page 2 of 2

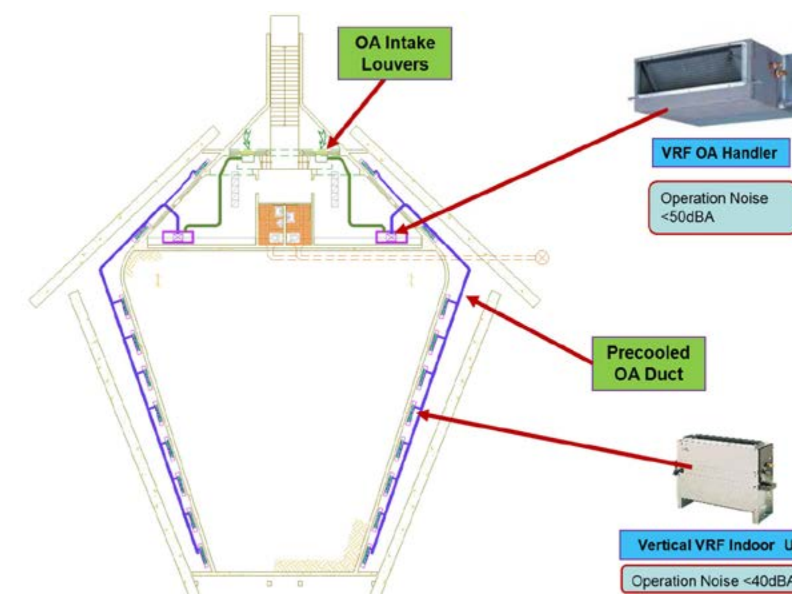
Attachment - B



Indoor Facility Installation – OA Intake at the rear side of B1F

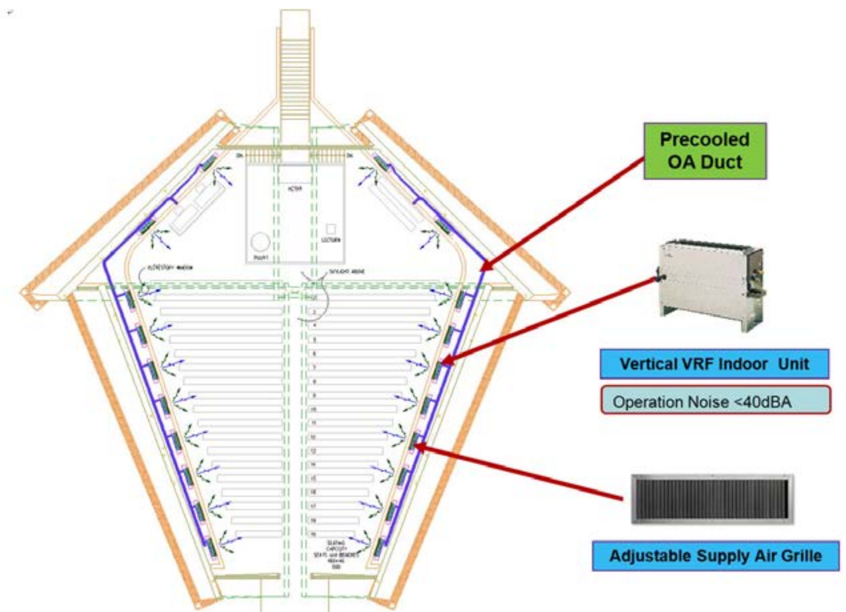
Outdoor air Issue - The minimum outdoor air required for 500 people in chapel is 1,300L/s (@ 2.5 L/s. person + 0.3 L/s. m 2), according to ASHRAE STD. 62.1 "Ventilation for Acceptable Indoor Air Quality".

Attachment - C



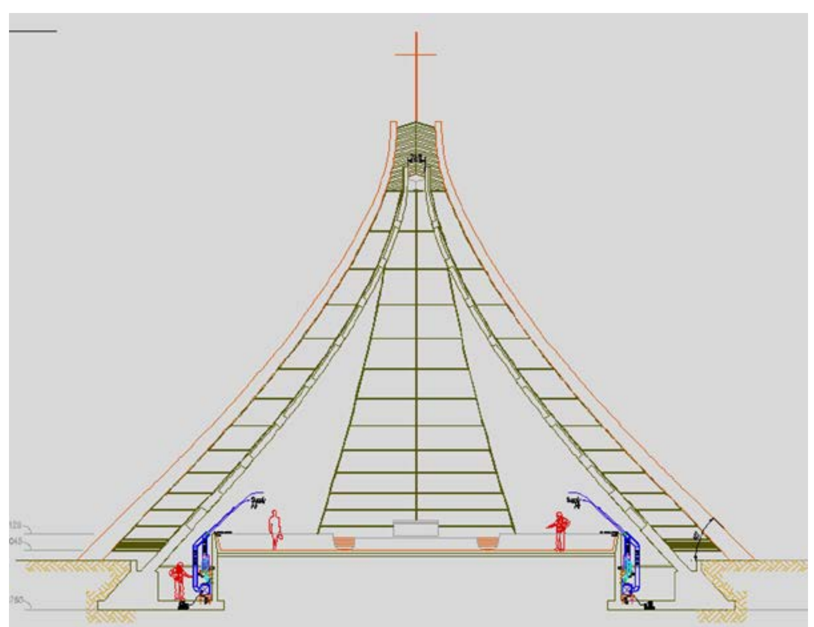
Indoor Facility Installation (B1F Plan)

Attachment - D



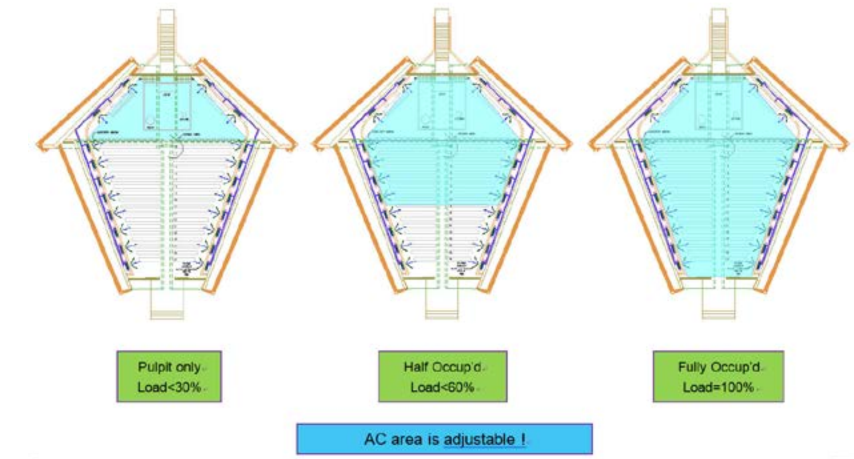
Indoor Facility Installation (1F Plan)

Attachment - E



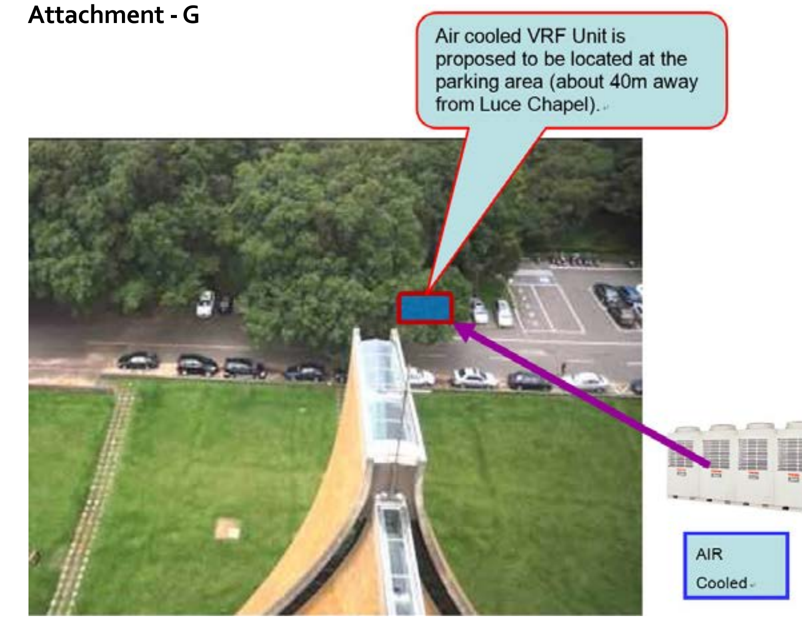
Indoor Facility Installation (Section)

Attachment - F

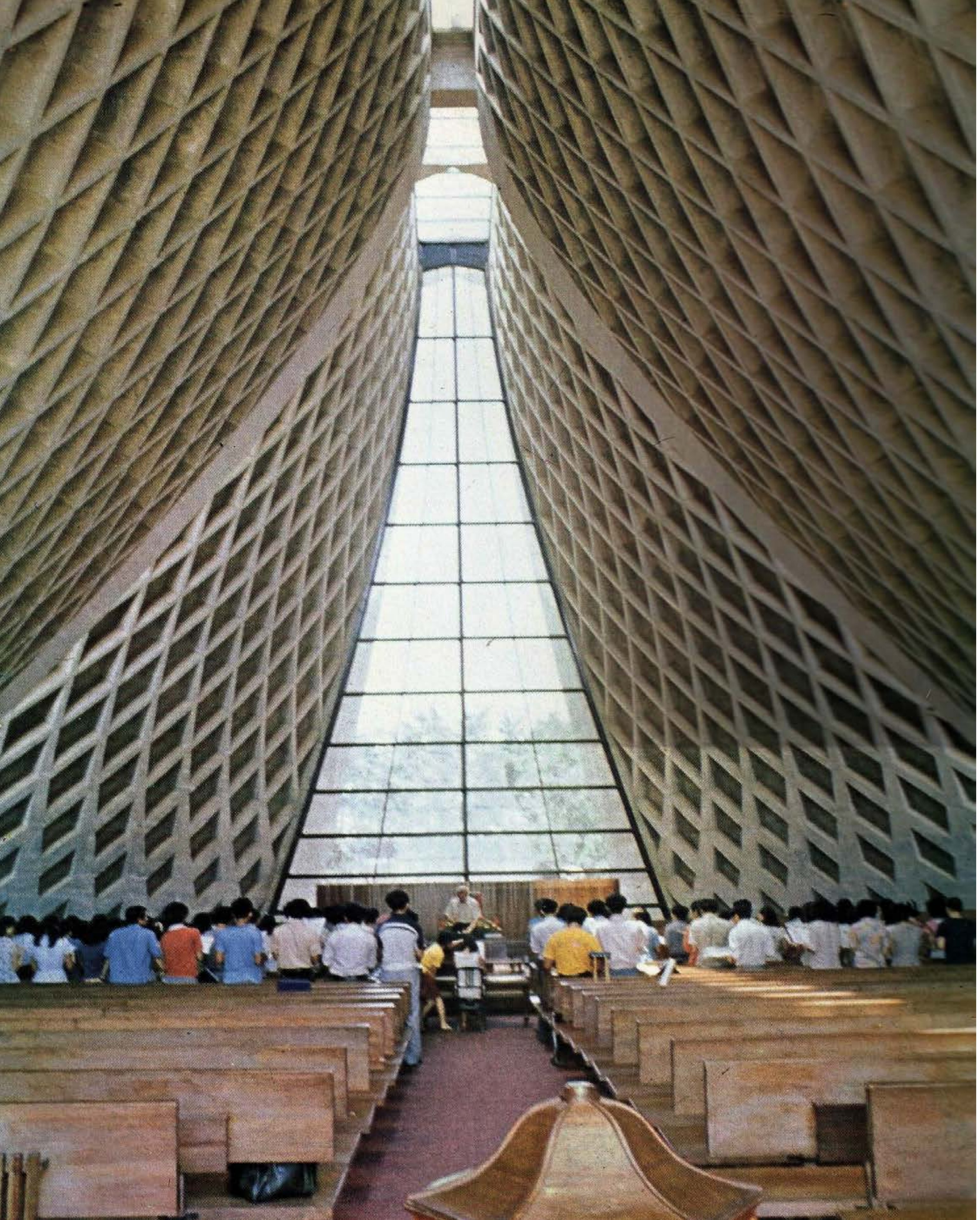


The number of running machines can be adjusted according to the demand of AC system load

Attachment - G



Outdoor Unit Installation



8. Acoustic Diagnostics and Suggestions Regarding the Luce Chapel

Acoustic Environment of the Luce Chapel

- Activities involving electroacoustic settings, such as worship services, lectures, etc.
- Activities without electroacoustic settings, such as choir and classic music concert.

The Result of the Acoustic Diagnostic Onsite Investigation of the Luce Chapel

A.Reverberation Time (RT) Test in the Empty Chapel (July 1st 2014)

Frequency (Hz)	125	250	500	1000	2000	4000
RT (second)	3,1	3,1	2,9	2,8	2,5	2,0

Even with the presence of an audience (around 300 people) in the chapel (volume 4428m3), the RT value could be reduced 0,2-0,3sec at the mid-frequencies, making the environment suitable for music performances. However, the false applications of the current acoustic sound system (correlation between the locations of speakers and projecting directions) impact the sound clarity within the chapel. Therefore, the subsequent acoustic improvement projects should focus on improving the projecting direction and modulation of sound efficiency between direct and echo sounds, which would improve the present speech intelligibility and maintain the thoroughness of music performances. The architectural RT value is rather intact; therefore is not in need of renovation.

B.Speech Intelligibility (STI according to IEC 60268-16 2003; tested by applying the current acoustic system)
STI (Speech Transmission Index) : 0,41 (poor intelligibility)
RASTI (Rapid speech transmission index) : 0,39 (poor intelligibility)

8.1 The Miho Chapel

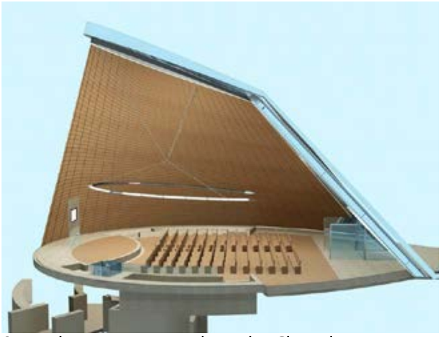
8.2 "AXYS Intellivox" in the Miho Chapel

Analysis of the Current Acoustic Environment (conducted in July, 2014)

The low speech intelligibility of the Luce Chapel caused by the adoption of the present acoustic system has nothing to do with the obstructions within the architectural environment. Although longer reverberation does impact speech intelligibility, reverberation time is not the only criterion that influences human hearing. The sound clarity and speech intelligibility within the chapel is determined by the ratio of direct and reverberated sound. The current acoustic system places the speakers at the sides of the chapel with the speakers facing upward, which does not project the sounds directly to the audience. Rather, the sounds are projected to the ceiling, rebounded back and forth in the air and then reaching the audience as a sound mixture with a low STI of 0.4, which is far below the standard 0.6~0.7 for clear speech intelligibility.

Suggestion on Sound Quality Improvement

1. The volume, appearance, shape, and finishing materials are the fundamental characteristics of the chapel, and are in need of renovation no other than cleaning. Even the acoustic diffusion caused by the 30cm deep rhombic RC beams creates positive sound effect. The current RT of 2.9 sec at 500HZ is essential for classical and religious music (traditional Christian music) performances. The architecture does not need any further renovation other than the improvement on air conditioning system and rearrangement of speaker positions and projecting directions. The acoustic consultants deliberately visited the 97 year old I.M. Pei in New York to ascertain the main goals for the acoustic improvement of the chapel.
2. Another improvement recommendation is to change the current public address system to the special "Sound Column" as the main acoustic source at the two sides of the preaching area. Its narrow acoustic directivity will be able to project direct sound to the audience seats. The presence of the audience will absorb most of the sounds, and few of the sound energy will reflect to the top of the RC beams and slabs, optimizing the energy radio between direct and reverberant sound and improve the speech intelligibility considerably.
3. One of the sound column systems to be recommended is the Swiss made "AXYS Intellivox," which was also adopted at the Rothenberg Modern Art Museum and Miho Chapel (Fig.7.1) of the Miho Museum established in 2013 in Kyoto, Japan. The building of these architectures both worked in close collaboration with I.M Pei. With a full house reverberation time of 1.4 second, the speech intelligibility of Miho Chapel was refined after applying the sound column (Fig.7.2). Resonating in look and function, Miho Chapel, built 60 years after the Luce Chapel, is still an interesting reference for comparison and contrast. However, the interior material of the Luce Chapel is more reflective than the materials used in the Miho Chapel, leaving a longer reverberant time length. Therefore, this research suggests the adoption of a higher sound column with the same speech intelligibility and stronger sound projection. However, an acoustic sound simulation is necessary for further assessment and design resolution.


8.3 Lighting system in the Miho Chapel


8.4 Lighting system in the Miho Chapel


8.5 Lighting system in the Miho Chapel

Suggestions on Acoustic Improvement

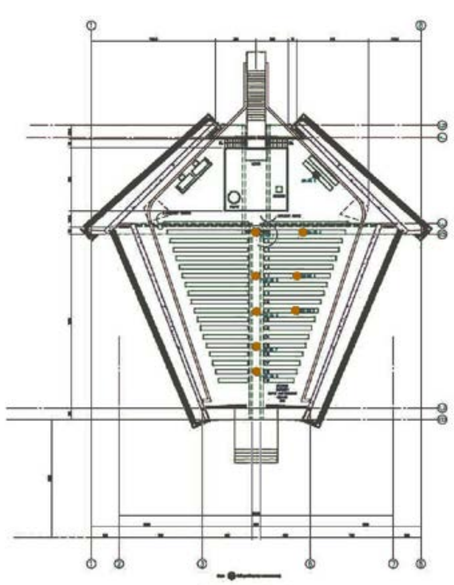
Base on the measurements and analyses of the given data, the acoustic consultant recommended keeping the architectural structure of the Luce Chapel with an adoption of sound column which provides stronger sound projection. This will maintain the fullness of religious music, and enhance the STI (speech intelligibility) of prayer and lectures from 0.4 to 0.65. According to our years of collaborating experiences with Mr. I.M. Pei's, we would suggest retaining the design intentions of the original designer and improve the acoustic defects of this historical architecture under the limited budget of the university.
During our visit in July 2014, we also took notice on problems regarding the lack of natural lighting, which is especially troublesome for reading among the audience seats in the chapel. Similar issues were also apparent in the Miho Chapel. To solve this problem, the lighting improvement design of the Luce Chapel can refer to the ring shaped spot light system used in the Miho Chapel designed by Mr. I.M. Pei (Fig.8.3~Fig.8.5).

Appendix - Acoustics Measurement Result

A.1 Measurement Description

Purpose: Room acoustic parameters of the Luce Chapel.
Location: The Luce Chapel, Tunghai University, Taichung
Measuring Date: 1 July, 2014
Measuring personnel: Prof. Albert XU, Dr. C.Y. Cheng, Dr. P.L. Li

A.2 Measuring Positions


8.6 Measuring positions


8.7 Measurement photo

A.3 Measuring Instruments

The following instruments were used for the measurement.
1. Amplifier system and Speakers at the Luce Chapel
2. Microphone, B&K Type 4190
3. Sound level meter, CNS 7129, Type 1
4. Microphone calibrator
5. Acoustic Front-end, B&K Type
6. DIRAC Room Acoustics Software, B&K Type 7841

A.4 Measurement Results

Table8-1 Reverberation Time

Frequency (Hz) / (Position)	Reverberation Time in the Empty Chapel						
	125	250	500	1k	2k	4k	8k
1	3.0	3.0	2.9	2.6	2.7	2.1	1.4
2	3.3	3.0	3.0	2.9	2.6	2.1	1.3
3	3.1	3.0	2.8	3.0	2.6	2.0	1.3
4	3.1	3.2	2.9	2.8	2.4	2.1	1.3
5	2.9	3.0	3.0	2.6	2.5	2.1	1.3
6	3.0	3.1	2.7	2.8	2.4	2.0	1.3
7	3.3	3.0	3.0	2.7	2.5	2.1	1.5
8	3.0	3.0	2.7	2.8	2.4	2.1	1.3
9	3.2	3.2	2.8	2.8	2.7	2.0	1.3
Average RT(s)	3.1	3.1	2.9	2.8	2.5	2.0	1.3

Table 8-2 Speech Intelligibility (STI)

Position	Empty Chapel	
	STI	RASTI
1	0.45	0.43
2	0.44	0.40
3	0.41	0.38
4	0.40	0.38
5	0.39	0.37
6	0.38	0.35
7	0.37	0.36
8	0.37	0.34
9	0.51	0.49
Average value	0.41	0.39

* The measurement were conducted and evaluated according to ISO 3382 and IEC 60268-16.

9. The lighting plan of Luce Chapel, when it was constructed

The original lighting plan of the Luce Chapel

There were not many lighting construction according to the original diagram. The plan was to illuminate the chapel by installing spotlights beside the skylight. Although it is difficult to distinguish the original light source from the diagram, it is very likely to be halogen bulbs owning to historical background and the size of the feature on the original diagram. The halogen bulbs were probably around 150~300-watts with a beaming angle of 8 degree according to the original diagram. This would have had a great impact on the thermal load of the skylight glass. The bulbs were not expected to be used for long hours and were probably not able to carry a large amount of wattage. Thus, the light source was very likely to be halogen bulbs at 150~300-wat with 8 degree in beaming angles.

In addition, mercury lamps were installed at the indentations at the sides of the chapel. These lamps were probably added to enhance the spatial characteristics of the chapel. Although the luminous intensity and beaming degree of the light source cannot be observed from the original plan, they are very likely 60~100-watt light bulbs with a diffused luminous intensity judging from circumstances and photo documents.

As for the exterior of the chapel, we assume that four spotlights with 500~1000-watt sodium lamps were selected to illuminate the external walls of the whole building. However, details of the light source were not discovered in this investigation.

According to diagrams and photo documents of the chapel, the above lighting features were most likely the light sources used to compose the artificial lighting environment in and out of the chapel.

The current lighting design.

The original lighting features have been added or renovated with 3 distinctive alterations which are listed as the following:

A. Spotlights at the sides of the skylight were not applied.
   This design might have been eradicated for its inconvenience in maintenance, especially under high frequency of maintenance.
B. Upward lights at the indentations at the both sides of the floor have been changed from spotlights to straight tube fluorescent lights.
C. The reason could have been the increase number of nighttime visitors or insufficient lighting in the first place.

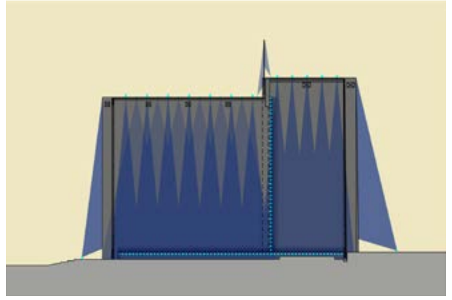
Straight tube fluorescent lamp apparatus were installed on the profile of a ceiling slab to illuminate the pulpit to solve the insufficient lighting at the chancel.
These changes were made according to the actual usage of the chapel, thus future lighting plans should take these alterations into consideration before proposing further improvement suggestions.

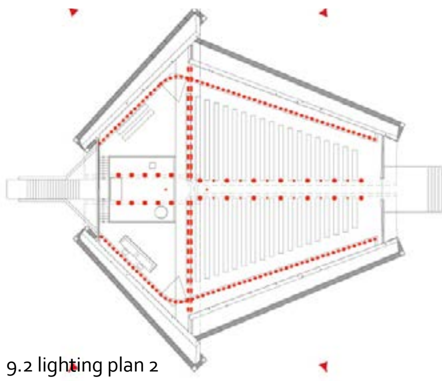
Lighting plans for the future- "Maintenance"

There are two important goals for the coming renovation. One is to attract local residents, students and faculty on campus with the light of the chapel. Another is to restore to the original lighting plan. Although it is important to come up with a good lighting plan, visitors from will come and go generations after generations, and so will the managers of the chapel. Therefore, it is equally essential to strengthen the current maintenance management in order to restore the original lighting and pass it to the coming generations.

Renovation Plan

1. All the original light features shall be converted to LED. This shall be able to restore the original lighting effects while reducing the cost of maintenance.
2. For spotlights above the skylight, two kinds of LED spotlights will be installed outside the chapel. 24 spotlights with 45 watts and 11 degree in beaming angel will be installed along with 14 spotlights at 12-watts and 25 degrees beaming angle. The life span of the light source will be increased to 40,000 hours, which is 20 times more than the current 2000-hour life span. This shall drastically reduce the frequency of maintenance and bring down the electricity demand from 3-kilowatts to 1.4 kilowatts. As for the interior lighting, the seating area shall also obtain enough luminous intensity at approximately 300lx.
3. As for lighting in both sides of the first floor indentations, upward spotlights with mercury lamps will be replaced with LED lined light (24W/m) and its diffuse light will be installed upward. This can reduce the electricity energy consumption from the original 1.8 kilowatts to 1.3-kilowatts. Moreover, the problem of inconsistent illumination caused by spotlight intervals shall be resolved. The ceiling will also be able to receive homogeneous lighting, which was impossible at the time of construction.
4. The position where straight tube fluorescent lamps apparatus are placed at the profile the ceiling slab behind the pulpit is very disturbing in appearance. They shall be removed and replace with LED tape light (10W/m), which will be hidden at a position above eye level, and be made invisible to the congregation.

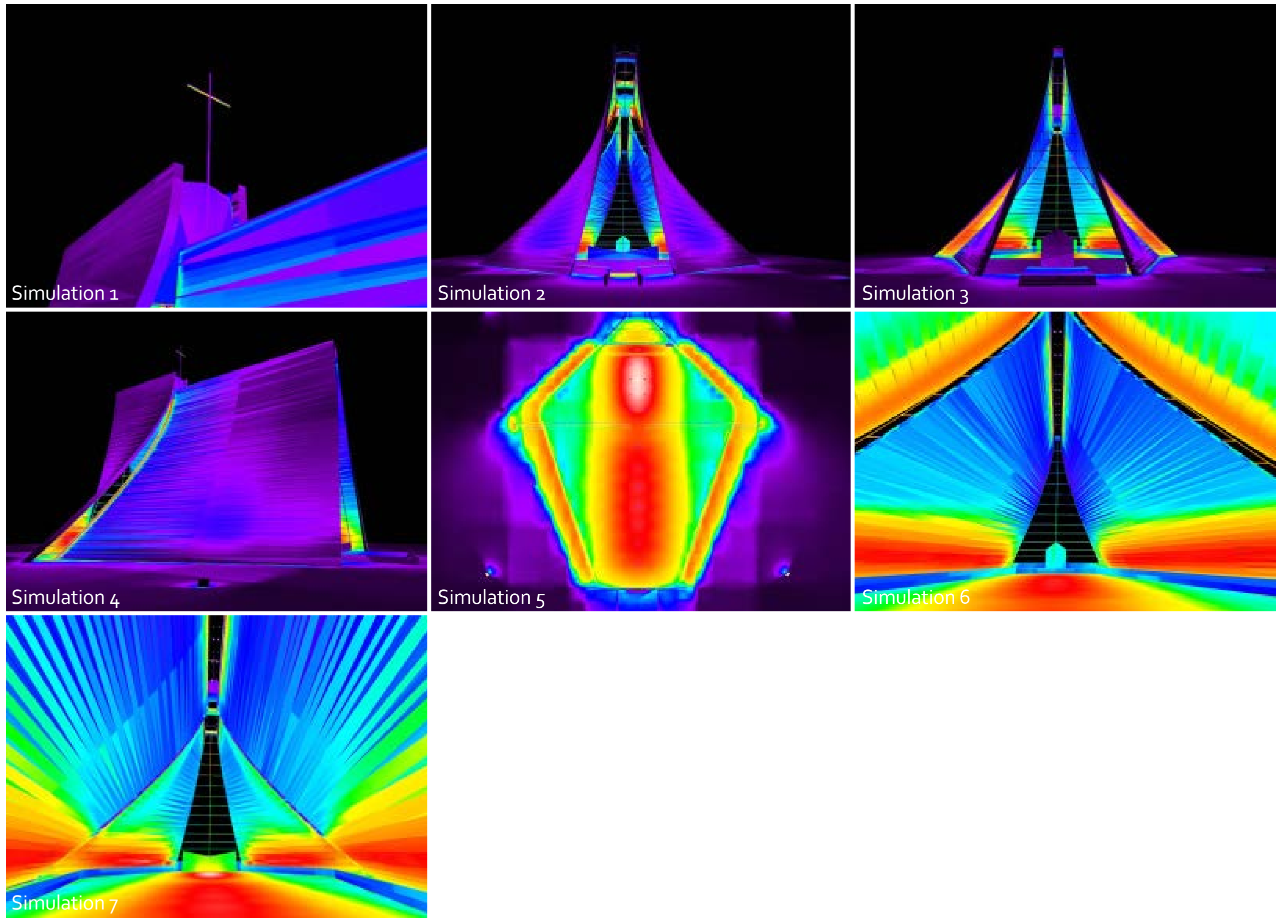

9.1 lighting plan 1


9.2 lighting plan 2

5. Concerning the exterior, the spotlights with sodium lamp will be replaced with 120 watts LED diffused projection lights. This will reduced the energy consumption from 2 kilowatts to 0.5 kilowatts without compromising the quality of light.
6. All color temperature will be warm white incandescent light to unify the texture of light and complement the historical value of the building.
7. Dimmer switches will be provided to meet the demand of different occasions.
8. Temporary power source and stands will be installed at the chancel for events such as concerts.

Conclusion

These renovation suggestions are compiled to restore the effects of the original lighting design and to resolve current maintenance problems. Our principal is upgrading the current light source to the latest lighting features at the original spots. We expect local residents, students, and faculty on campus to increase their number of visits and utilization of the chapel upon the completion of this renovation. The main concept of this renovation is to increase the satisfaction of visitors, and propose a feasible maintenance plan for visitors and managers for the generations to come. We look forward to the day for the chapel to restore its former glory.



9.3 Simulation

10. Fire Services Review of Henry Luce Memorial Chapel

The Luce Chapel was built under a period of history when the National Building Act and National Fire Services Code was still rather slack, leaving the Henry Luce Memorial Chapel to be without an legal usage permit to this very day. Viewing the current strict building construction and fire prevention regulations, getting a legal usage permit is no longer an easy task. This project presents an overall review involving the installation of fire safety equipment and an executable scheme.
Here are some basic facts on the measurement of Henry Luce Memorial Chapel: The first floor area is 410.03 m2 accompanying the underground area of 70.68 m2, and the total floor measure is 480.71 m2. Its use falls in the category of auditorium without sufficient open windows and opening. According to the "Standard for Installation of Fire Safety Equipment Based on Use and Occupancy (amended on May 1st 2013; promulgated under Order Tai-Nei-Hsiao-Tzu No.1020821188 on May 1, 2013, effective from the same day.) ", fire extinguishing, alarm, evacuation equipment, as well as necessary equipment for fire rescue in case of the Luce Chapel includes the following: Fire extinguisher, hydrant, automatic sprinkler system, automatic fire alarm equipment, emergency broadcasting equipment, indication equipment (exit sign lamp, direction indicator lamp, audience guiding lamps, and signs), as well as smoke control equipment (smoke control equipment inside emergency elevator and special safety stairway, and indoor smoke control equipment). Installation of all the above fire safety equipment other than the fire extinguisher and indication equipment is going to have a great impact on the overall appearance of the interior.
Under the given circumstances, the lack of permit still needs to obtain its legal usage permission. Suggestions of various possibilities are listed as the following. First of all, Henry Luce Memorial Chapel should obtain the cultural heritage certification, then designate or register the assets in accordance with relevant law procedures. In Taiwan, facilitating the restoration and reuse of monuments, historical buildings and settlements, and matters relating to the construction management, land use and fire safety of such sites shall be exempted, in whole or in part, from the restrictions of the Urban Planning Law, Building Code, Fire Act

and other related laws and regulations. The central competent authority together with the Ministry of the Interior shall prescribe the review procedures, inspection standards, restrictions, requirements and other matters that shall compliance with other methods. Secondly, according to Regulations for Building Administration, Land use, and Fire Safety of Restoration and Reuse of Monuments, Historical Buildings and Settlements (2010.10.19 Amended; promulgated under Order Tai-Nei-Ying-Tzu No. 0990819908.), when the owner, user or manager of Henry Luce Memorial Chapel encounters difficulty in applying the law, act, or code set forth in the preceding paragraph, based on the goal of the cultural heritage conservation and preservation and the analysis of site and environmental disaster risk, the response plan shall be proposed and submitted to the competent authority. Above all, on account of the structural simplicity of the chapel, the limited evacuation routes and interior combustibles, the fire prevention plan shall exclude several items mentioned above. Furthermore, a performance review shall be submitted to the central regulating authority for approval. The building usage permit of Henry Luce Memorial Chapel shall be approved by the Cultural Affairs Bureau after the submission of a relevant fire prevention plan.

11. Appendix Budget estimate

Budget estimate

路思義教堂 修復及再利用工程
Luce Chapel Restoration / Revitalization

編號 No.	工程項目 category	單位 unit	數量 qty	單價 unit cost	複價 subtotal	備註 remarks
	A 壹期工程 phaseI					
壹	發包工程費 Contract fee					
一	工程施作費 Project Operation Fee					
(一)	假設工程(鷹架) scaffold and contemporary works	式	1	4,282,430	4,282,430	
(二)	外牆磁瓦、結構體修復及防水工程 exterior ceramic tiles, structural restoration, waterproofing	式	1	4,076,100	4,076,100	
(三)	門窗及排水工程 fenestration, drainage	式	1	7,388,750	7,388,750	
(四)	地坪及雜項工程 flooring and miscellaneous works	式	1	8,789,450	8,789,450	
(五)	設備工程 HVAC	式	1	13,987,020	13,987,020	
	(一)~(五)小計 sub-total				38,523,750	a1
二	勞工安全衛生設備管理費 OSHA compliance administration	式	1	423,761	423,761	a1*1.1%
二	包商利潤及管理費雜費(含工程營造保險費) contractor admin / insurance	式	1	3,852,375	3,852,375	a1*10%
三	工程品管費 Quality Assurance	式	1	770,475	770,475	a1*2%
	二 ~ 三小計 sub-total				5,046,611	b1
四	營業稅 5% state tax	式	1	2,178,518	2,178,518	(a1+b1)*0.05=c1
	發包工作費合計 total contract cost				45,748,879	a1+b1+c1=d1
貳	設計監造費 design/supervision 3,467,000					
參	工程管理費 construction management				635,000	
肆	工作報告書 reports &documents				1,500,000	
伍	空污費 pollution control				137,000	
	總計				51,487,879	

工程預算書詳細表
路思義教堂 修復及再利用工程 Luce Chapel Restoration / Revitalization

項 次	項 目	單 位	數量	單價	複 價	備 註
壹	發包工程費 contract					
一	**假設工程 (temporary works)**					
1	工程告示板 75×120 ㎝租金 billboard rental	式	1	5,750	5,750	
2	臨時工務所及辦公設備費用 temp office/equip.	式	1	460,000	460,000	
3	警示燈及臨時水電設備費用 safety temp power supply	式	1	207,000	207,000	
4	甲種圍籬安裝及拆除(含修護及警告標示) fence/warning signs (install and removal)	M	250	1,380	345,000	1.2mm*240cm
5	甲種圍籬大門 (4M 寬滑動門) 安裝及拆除 controlled gate (install and removal)	組	1	6,900	6,900	
6	框式施工架及防塵網(含防護繩)租金 scaffolding and protective nets (rental)	M^2	3,800.00	403	1,531,400	含上下設施 incl. lifting device
7	室內施工平台租金 interior construction platform (rental)	M^3	14,640.00	92	1,346,880	含上下設施 incl. lifting device
8	門窗鋼框解體編碼調查 fenestrations disassemble and codings	式	1	74,750	74,750	
9	木作家具編碼調查 fufnitures disassemble and cdings	式	1	57,500	57,500	
10	施工架外掛大圖輸出帆布 protective covering/canvas	式	1	103,500	103,500	
11	施工大樣圖及竣工圖繪製 construction & shop drawings, as-built documents	式	1	40,250	40,250	
12	檢驗費用 testing/experiments	式	1	69,000	69,000	
13	試做費用 mock-ups	式	1	34,500 3	4,500	
	小計 sub total				4,282,430	
二	**外牆磁瓦、結構體修復及防水工程 exterior ceramic tiles, structural restoration, and waterproofing**					
1	內外牆中性清潔劑清洗 Neutral detergent for exterior cleaning sample tests required	M^2	2,928.00	400	1,171,200	須先試做
2	外牆磁瓦灰縫剝損處修補 exterior grout(damaged within ceramic tiles) repair	式	1	172,500	172,500	

項 次	項 目	單 位	數量	單價	複 價	備 註
3	外牆磁瓦嚴重損壞處以庫存磁瓦換補 exterior tiles replacements	式	1	460,000	460,000	依解體調查後評估結果決定 subject to condition/evaluation after dismounting
4	結構體裂縫壓力灌注 EPOXY structural crack pressure filling with epoxy	M	240	1,380	331,200	
5	結構體鋼筋鏽蝕處，鋼筋除鏽置換，無收縮水泥砂漿修補 structural steel restoration works	式	1	138,000	138,000	
6	既有清水混凝土表面清水漿修飾 exposed concrete surface treatment	式	1	230,000	230,000	
7	基礎 RC 梁外防水施做 foundation RC restoration and water proofing	M	72	8,050	579,600	含開挖 incl. required earth work
8	排水滲透管及卵石回鋪，表面覆土植草 storm drainage, gravel refill, and lawn work	M	72	13,800	993,600	
	小計 sub total				4,076,100	
三	**門窗及排水工程 fenestration and water proofing**					
1	門窗鋼框去漆 steel frame paint removal	式	1	414,000	414,000	
2	門窗鋼框臨時支撐架 temporary scaffolding for steel frame dismounting	式	1	86,250	86,250	
3	門窗鋼框落架及運費 steel frame dismounting and transportation	式	1	172,500	172,500	含玻璃拆卸 incl. glass removal/disposal
4	東面門窗鋼框除鏽防鏽後刷漆 east-side fenestration rust-proofing and paint	樘	1	834,900	834,900	
5	西面門窗鋼框除鏽防鏽後刷漆 west-side fenestration rust-proofing and paint	樘	1	1,086,750	1,086,750	含安裝，橡膠墊更換 Incl. installation, rubber sealant
6	南面側窗鋼框除鏽防鏽後刷漆 south-side fenestration rust-proofing and paint	樘	1	258,750	258,750	
7	北面側窗鋼框除鏽防鏽後刷漆 north-side fenestration rust-proofing and paint	樘	1	258,750	258,750	
8	新裝 Low-e 玻璃 new Low-E glass/glazings	才	2,772.00	690	1,912,680	含油灰防水填縫 Incl. putty joints
9	天窗更改 skylight restoration	M2	25.65	13,800	353,970	改善方案一 according to improvement option 1 st .
10	新做不鏽鋼氟碳烤漆通風百葉及天溝 newstainless-steel Fluorocarbon paint louver/gutter	M	47.6	34,500	1,642,200	改善方案一 according to improvement option 1 st .

項 次	項 目	單 位	數量	單價	複 價	備 註
11	排水管疏通及新做內管 roof drainage rooting / new drain pipes	支	4	92,000	368,000	
	小計 sub total				7,388,750	
四	**地坪及雜項工程 flooring and miscellaneous**					
1	現有耐磨地板及夾板拆除 removal of existing florring	M2	410	345	141,450	含垃圾清運 incl. garbage disposal
2	新做隔振墊及 8 分柳安木實木地坪 new hardwood flooring with shock-proof padding	M2	410	9200	3,772,000	含表面處理 incl. s urface treatments
3	木作家具去漆 millwork - paint removal	式	1	1035000	1,035,000	
4	木作家具整修 millwork - restoration	式	1	2300000	2,300,000	依調查結果調整 subject to condition/ evaluation
5	木作家具刷護木油 millwork - new wood oil paint	式	1	1380000	1,380,000	
6	廁所管路，陰井及暗管疏通 Toilet renovation, sewer rooting	式	1	46000	46,000	
7	汙水處理設施更新 Sewage treatment and equipment updates	式	1	115000	115,000	
	小計 sub total				8,789,450	
五	**設備工程 Building Equipments**					
(一)	空調工程 HVAC	式	1	4,715,000	4,715,000	
(二)	照明工程 Light fixtures	式	1	5,750,000	5,750,000	
(三)	消防工程 fire safety compliance					
1	ABC 乾粉滅火器 10P fire extinguisher (dry power)	只	6	640	3,840	
2	CO2 滅火器 10P fire extinguisher (CO2)	只	4	3300	13,200	
3	乾粉滅火器放置架 fire extinguisher (dry power) hanger/housing	座	6	300	1,800	
4	CO2 滅火器放置架 fire extinguisher (CO2) hanger/housing	座	4	520	2,080	
	小計 sub total				20,920	

項 次	項 目	單 位	數量	單價	複 價	備 註
(四)	電氣工程 electric work	式	1	345,000	345,000	含開關箱，地面插座及管線 incl. access panel, floor receptacles incl. portable/travel cases
(五)	音響工程 acoustic work					
1	DSP 主動式音柱陣列揚聲器 DSP speaker set	支	2	437,000	874,000	
2	DSP 主動式超低音揚聲器 DSP woofer set	支	2	253,000	506,000	
3	數位混音器 digital multi-track mixer	台	1	862,500	862,500	含攜行箱 incl. portable/travel cases
4	無線分享器 WAP wireless access point device	台	1	4,100	4,100	
5	正面輔助揚聲器 Front auxiliary speaker	支	2	22,000	44,000	
6	正面輔助揚聲器 DSP 擴大機 Front auxiliary speaker DSP amplifier	台	1	34,500	34,500	
7	監聽揚聲器 (floor) Monitors	支	4	50,000	200,000	
8	監聽揚聲器 DSP 擴大機 (floor) Monitors DSP amplifier (floor) Monitors	台	1	70,000	70,000	
9	4CH 數位式無線麥克風 4CH digital wireless microphone	支	2	98,000	196,000	
10	2CH 數位腰包含頭戴麥克風 2CH digital lavalier headworn microphone	支	2	41,000	82,000	
11	無線手持平板控制器 Wireless flat panel controller	台	1	23,000	23,000	
12	管線及施工安裝費 acoustic system wiring and installation	式	1	65,000	65,000	含舊有設備拆除 incl. disposal of old equipments
13	系統調整及測試報告費 audio system testing and adjustments	式	1	80,000	80,000	
14	系統教育訓練及技術支援費 audio system training and tech supports	式	1	115,000	115,000	
	小計 sub toal				3,156,100	
	合計 total				13,987,020	