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Assessment of Composite Steel and Reinforced Concrete Systems: The Case of the New Atatürk Cultural Center

Çelik ve Betonarme Malzeme ile Oluşturulan Kompozit Sistemlerin Yeni Atatürk Kültür Merkezi Binası Üzerinden Değerlendirilmesi

Berrin ŞAHİN DİRİ[1*], Erdinç BEKAR[2]

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Abstract

Composite materials use combinations of materials that cannot meet the desired structural performance in the architectural field alone. The new Atatürk Cultural Centre had to be reconstructed on a site in Taksim Square where there are heavy vehicle and pedestrian traffic, and close to the city's rail transport network. This congestion compelled the entire construction team to adopt construction technologies that diverged from traditional techniques. The new building had to remain within some of the references of the old building, while at the same time making a new architectural and engineering step forward. A construction technology using a combination of reinforced concrete and steel components was the solution to many problems. The objective of this study is to evaluate the benefits of the reinforced concrete-steel composite system, to show that it is a more suitable construction technology for buildings with unique architecture under special conditions such as restricted building sites, large spans, seismic risk zones, and thus to draw the attention of the construction sector to the advantages of this system. To this end, an examination of the projects of the New AKM building was conducted, encompassing the collection of data through interviews with static and architectural offices, as well as electronic sources. The structural system of the building was then analysed using the 'illustrative case study' method. The study concluded that the utilisation of composite construction systems offers numerous advantages, including enhanced building load capacity, seismic resilience, accelerated construction processes, and reduced labour errors in special-use buildings located in urban centres.

Keywords: New AKM Building, Reinforced concrete-steel composite systems, Steel load-bearing systems, Composite flooring systems, Reconstruction.

Özet

Kompozit malzeme, mimari alanda istenilen yapısal performansı tek başına karşılayamayan malzemelerin bir arada kullanılarak üstün bir performans elde etme çabasından doğmuştur. Yeni Atatürk Kültür Merkezi'nin konum olarak çok yoğun araç ve yaya trafiğine sahip Taksim Meydanı'nda ve şehir içi raylı ulaşım ağının merkezi noktalarına yakın bir parselde yeniden inşa edilmesi gerekmiştir. Bu sıkışıklık, tüm inşaat ekibini geleneksel tekniklerden farklı inşaat teknolojilerine yöneltmiştir. Yeni binanın hem eski yapının bazı referansları içinde kalması hem de mimari ve mühendislik olarak yeni bir adım ortaya koyması gerekmiştir. Betonarme ve çelik yapı bileşenlerinin bir arada kullanıldığı bir inşaat teknolojisi, bu binada birçok soruna çözüm olmuştur. Çalışmanın amacı, betonarme-çelik kompozit sistemin avantajlarını değerlendirmek; sıkışık inşaat alanları, geniş açıklıklar, riskli deprem bölgeleri gibi özel koşullar altında kendine özgü mimariye sahip binalar için daha uygun bir yapı teknolojisi olduğunu göstermek ve böylece inşaat sektörünün dikkatini bu sistemin avantajlarına çekmektir. Araştırma, nitel bir vaka çalışması olarak yürütülmüştür. Bu kapsamda Yeni AKM binasının projeleri incelenmiş, statik ve mimari ofislerle yapılan görüşmeler ve elektronik kaynaklar üzerinden binanın yapısal sistemi, örnek olay incelemesi yöntemiyle analiz edilmiştir. Bu çalışma ile kompozit yapım sistemi kullanımının şehir merkezinde yapılan özel kullanımlı binalarda yapı yükü, deprem, hızlı yapım süreci, daha az işçilik hatası gibi birçok olumlu yönü olduğu sonucuna varılmıştır.

Anahtar Kelimeler: Yeni AKM binası, Betonarme-çelik kompozit sistemler, Çelik taşıyıcılı sistemler, Kompozit döşeme sistemleri, Yeniden yapım.

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[1] Mimar Sinan Fine Art University, Faculty of Architecture, Architecture Department, Istanbul, Türkiye. berrinsahindiri@outlook.com
[2] Mimar Sinan Fine Art University, Faculty of Architecture, Architecture Department, Istanbul, Türkiye. erdinc@iltay.com.tr
[*] Corresponding Author

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Extended Abstract

Introduction: In the 1920s, composite construction was predominantly employed for bridges requiring long-span capabilities. Since the 1970s, composite components have been used as wall and floor components in prefabricated modular homes and multi-story buildings. This construction system reduced the weight of the structure, allowed large spans, and provided fire resistance. After 1975, the important role of composite structures in civil and industrial buildings was proven, especially in multi-story buildings and factories (Pelke & Kurrer, 2015). The reinforced concrete in-situ construction method started to be used in the construction sector with the establishment of the cement factory in the 1950s in Türkiye and continued to dominate as developed. In recent years, reinforced concrete-steel composite structural elements and systems have been increasingly used and researched in countries such as Türkiye, which has a high seismic risk, and a construction tradition based on in-situ reinforced concrete construction.

Purpose: The aim of the study is to evaluate the advantages of the reinforced concrete-steel composite system on the New Atatürk Cultural Center structure and the construction process, to show that the reinforced concrete-steel construction system is a more suitable construction technology for buildings with distinctive architecture under special conditions such as cramped construction areas, large openings, and risky earthquake zones in Türkiye, and thus to draw the attention of the construction sector to the advantages of this system. For this purpose, the composite structural system of the New Atatürk Cultural Center building in Taksim, Istanbul, which was completed and opened for use on October 29, 2021, where reinforced concrete and steel structural systems are used together, is examined.

Method: The present study utilised information obtained from internet sources and projects, in addition to documents obtained from the Static Office of the New AKM Building. The rationales underpinning the selection of reinforced concrete-steel structural composite systems, and their attendant advantages in the construction process, were investigated. The present study was conducted with the objective of analysing the structural system of the New AKM building. To this end, a comprehensive data collection process was initiated, encompassing projects related to the New AKM building, interviews with relevant static and architectural offices, and online sources. The collected data were then subjected to rigorous analysis using the 'illustrative case study' method, a research approach that involves the detailed examination of a single case or event to gain insights into its mechanisms, characteristics, and implications. The presentation revealed the composite system, comprising a reinforced concrete-steel composite, as well as composite slabs, and the reasons for their use in blocks A and B of the project. A comparative analysis was conducted between reinforced concrete-steel composite systems and reinforced concrete and steel frame systems in terms of weight, cost, spatial requirements, and construction time.

Findings: AKM closed for renovation on May 31, 2008, and Tabanlıoğlu Architecture was given the renovation project. The building was demolished in March 2018 and rebuilt as the New AKM Building, which was completed 32 months after the groundbreaking ceremony. The cost was approximately TL 2.2 billion. The new building includes a 2,400-seat opera hall, an 802-seat theatre, exhibition halls, a library with 20,000 books, a Yeşilçam cinema, a music recording studio, offices, restaurants, and cafes (BBC News Turkish, n.d.). Examples of composite buildings constructed at the same time as the New AKM building include the Istanbul Museum of Modern Arts and the Istanbul Medeniyet University Library. Reinforced concrete-steel composite slabs and structural steel elements were used in both buildings. The Istanbul Modern building, which was constructed between 2016 and 2023, has an area of 10,500 m² and includes exhibition halls, multipurpose spaces, offices, and educational and cultural activity spaces spread over five floors. The building rests on reinforced concrete columns supported by steel with axes of 8.4x8.4m. The building is constructed with steel, concrete, and glass materials and architecturally maintains the industrial character of the adjacent warehouses (Şantiye Edergi, n.d.a). The Medeniyet University Library building, which is on the Göztepe campus of Medeniyet University and constructed between December 2018 and August 2020, has a total construction area of 28,000 m² and a cost of 93 million TL (Figure 17) (Şantiye Edergi, n.d.b). The main structural system of the building is a reinforced concrete frame system (average column axis 7x7m, columns 80x80cm, beams 40x60cm). In order to pass the openings of up to 15 m in the intermediate floors of the entrance section and not to put excessive load on the reinforced concrete system, a reinforced concrete-steel composite floor system was used in the sloping roof slab. In the terrace section at the rear of the building, 'V'-shaped steel columns were placed to support a pair of eaves that extends 33 m as a continuation of the roof. Since spaciousness and openness is desired in this area, more slender steel columns were preferred instead of reinforced concrete columns with thick cross-sections that need to be placed frequently (Otman, 2025). The New AKM building has a total construction area of approximately 3 times (95,600 m²/28,000 m²) that of the Medeniyet University Library building, and the construction time of the library is 22 months; New AKM will be completed in 32 months.

Conclusion: Today, reinforced concrete construction is more widespread than other systems due to the considerable number of trained technical teams and workers and its relatively lower cost. However, the structural advantages of reinforced concrete-steel composite systems, such as greater seismic safety due to their lightness and ductility and more economical construction on soils with low bearing capacity, should not be overlooked. Although the ground of the new AKM building is not weak, the building it replaces has a height problem that had to be overcome. For this reason, the 2,040-seat Opera Hall in Block A was constructed using structural steel. In order to eliminate formwork and reduce the weight of the building, the 39.5 metre diameter, 27.5-metre-high

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auditorium was constructed in a flattened ellipsoid shape with steel trusses consisting of HEB700 ribbed ellipsoid columns and steel trusses with HEB600-300-200 elements resting on 80 x 80 cm reinforced concrete columns. The structure, which would have weighed 89,350 tonnes had it been constructed entirely in reinforced concrete, was constructed using structural steel for 85,600 tonnes, achieving a weight reduction of 4.4%. Today, reinforced concrete construction is more widespread than other systems due to the significant number of trained technical teams and workers and its relatively lower cost. However, the structural advantages of reinforced concrete-steel composite systems, such as greater seismic safety due to their lightness and ductility and more economical construction on soils with low bearing capacity, should not be overlooked. Although the ground of the new AKM building is not weak, the building it replaces has a height problem that had to be overcome. For this reason, the 2,040-seat Opera Hall in Block A was constructed using structural steel. In order to eliminate formwork and reduce the weight of the building, the 39.5 metre diameter, 27.5 metres high auditorium was constructed in a flattened ellipsoid shape with steel trusses consisting of HEB700 ribbed ellipsoid columns and steel trusses with HEB600-300-200 elements resting on 80 x 80 cm reinforced concrete columns. The structure, which would have weighed 89,350 tonnes had it been constructed entirely in reinforced concrete, was constructed using structural steel for 85,600 tonnes, achieving a weight reduction of 4.4%.

Keywords: New AKM Building, Reinforced concrete-steel composite systems, Steel load-bearing systems, Composite flooring systems, Reconstruction.

INTRODUCTION

The seminal study of composite beams in the United States was conducted by Caughey and Scott in 1929, marking a pivotal moment in the field's development. At that time, composite construction was employed principally in the construction of bridges that were required to span considerable distances. The American Association of State Highway Officials (AASHTO) published the first design specifications for composite bridges. Subsequently, the Federal Republic of Germany incorporated provisions for the design of composite structures within its building codes. These specifications were developed throughout 1961. Subsequent research in this field has been pursued by numerous researchers, including Fisher, Daniels, and Slutter (1972), Johnson, and Hope-Gill (1976). Since the 1970s, composite components have been utilised in the construction of wall and floor elements in prefabricated modular homes and multi-storey buildings. This approach resulted in a reduction of the structure's weight, enabled the construction of larger spans, and ensured the presence of fire resistance. Following 1975, the pivotal function of composite structures in civil and industrial buildings was substantiated, particularly in multi-storey buildings and factories (Pelke & Kurrer, 2015).

The utilisation of composite elements and systems in multi-storey buildings increased after the 1970s and in large-scale and special-use buildings after the 1980s. There are numerous reasons for this phenomenon. These include the increase in earthquake acceleration magnitudes, construction in narrow areas that do not allow the formation of construction sites in the city, the shift in architectural form demands from linear construction to multi-surface, curvilinear forms, and the demands for openings and consoles that push the material limits for today's conditions, the desire to overlap spaces with different uses in vertical planning, and the increase and constant change in wind and storm forces due to climate change. The utilisation of composite structures in civil construction on a global scale, particularly in the context of high-rise buildings, is indicative of their efficacy in meeting the requirements of bearing capacity. This is achieved through the use of compact structures, moderate cross-sections, and expeditious construction speeds (Tuan Long et al., 2022).

The composite construction system made its entry into the Turkish construction sector at a comparatively late stage. The utilisation of reinforced concrete in-situ construction methodology was initiated within the construction sector with the inception of the cement factory in the 1950s. This methodology has since remained a predominant technique within the sector. Half-tunnel formwork technology was extensively utilised in the construction of multi-storey mass residential buildings between 1980 and 2000. Subsequently, this technology was superseded by a reinforced concrete skeleton system incorporating a hollow slab. Since 2020, the construction sector has persisted in the development of buildings employing a reinforced concrete skeleton system with a column and slab configuration. In recent years, the utilisation

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and research of reinforced concrete-steel composite structural elements and systems have seen a marked increase in countries such as Türkiye, which is characterised by a high seismic risk and a construction tradition that is predicated on in-situ reinforced concrete construction.

Research Problem

In-situ reinforced concrete construction systems have been extensively utilised in Türkiye since the mid-20th century, owing to enhanced comprehension of the reinforced concrete construction system and more economical labour and material costs. Despite the fact that composite construction is a more suitable technology for buildings with distinctive architecture and multi-storey buildings in order to reduce vibrations caused by wind load and building load, especially in multi-storey buildings, composite structures are very few in our country. The primary factors contributing to the limited adoption of composite construction systems in Türkiye can be attributed to the paucity of standards and regulations that could provide engineers with clear guidelines, the high cost and labour-intensiveness of production due to the limited availability of qualified teams and organisations to undertake this work, and the relative unpopularity of steel structure technology.

Aim of the Research

The study discusses composite systems formed with steel and reinforced concrete materials, evaluating their positive and negative aspects according to contemporary conditions. The objective of the research is to evaluate the advantages of the reinforced concrete-steel composite system on the New Atatürk Cultural Centre structure and the construction process. It is hypothesised that the reinforced concrete-steel construction system is a more suitable construction technology for buildings with distinctive architecture under special conditions, such as cramped construction areas, large openings and risky earthquake zones in Türkiye. The study will also draw the attention of the construction sector to the advantages of this system. The present study examines the composite structural system of the New Atatürk Cultural Centre building in Taksim, Istanbul. The building was completed and opened for use on 29 October 2021, and its structural systems consist of reinforced concrete and steel.

Research Hypothesis

Reinforced concrete-steel composite construction systems have been demonstrated to offer certain advantages. The primary advantages of these materials are twofold. Firstly, their low weight facilitates a high load-to-weight ratio. Secondly, their ductility renders them more resistant to seismic activity. Furthermore, the quality of the structural elements can be regulated, thereby reducing the necessity for formwork, enhancing the construction speed of the edifice, decreasing the dimensions of the elements, and facilitating the integration of subsequent structural components in reinforced concrete-steel composite systems. The hypothesis of this study is that a reinforced concrete-steel composite structure has significant advantages for the building and construction process. Nevertheless, these advantages are frequently disregarded in numerous projects within Türkiye.

Aim of the Research

The present study examines the reinforced concrete-steel composite construction system. The construction system is evaluated by explaining the structural system, construction method, and elements used in the A and B Block Art Gallery of the reconstructed New AKM building in Taksim, Istanbul. The paper sets out to demonstrate the advantages of the reinforced concrete-steel composite construction system over the reinforced concrete and steel structural systems.

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METHOD

The present study utilised information obtained from internet sources, in addition to projects and documents obtained from the Static Office of the New AKM building. The rationales underpinning the selection of reinforced concrete-steel structural composite systems, and their attendant advantages in the construction process, were investigated. The data presented herein has been collected through the projects of the New AKM building, interviews with static and architectural offices, and online sources. The structural system of the building has been analysed using the ‘case study’ method. The presentation revealed the composition of the reinforced concrete-steel composite system, the rationale behind the utilisation of composite slabs in blocks A and B of the project, and the underlying principles that guided their selection. A comparative analysis was conducted between reinforced concrete-steel composite systems and reinforced concrete and steel frame systems. The analysis drew on a range of metrics, including weight, cost, spatial requirements, and construction time.

Findings and Evaluation

Structural elements, such as columns, beams, slabs, shear walls and stairs, that are fabricated using multiple materials to achieve the desired physical and mechanical properties are designated as composite members. In a similar manner, the structural system of a building can be formed by combining various structural elements. The utilisation of diverse materials, whether across the entirety of the structure or targeted to specific components, has the potential to endow the system with a range of properties. The design and consideration of such applications is informed by a range of factors, including the function of the building, the height of the floor, the floor area, the location, the characteristics of the soil, the climatic conditions, and the period of construction. In this context, the properties of steel, reinforced concrete, and reinforced concrete-steel frame composite systems are briefly explained, and then the New AKM building is presented and evaluated.

Steel Structures

Steels with low carbon content, containing manganese, silicon, copper, and sulphur elements, especially phosphorus and nitrogen, resulting from the production raw materials and production method, hot-formed and sometimes cold-drawn steels are termed ‘structural steels’. Structural steels are employed in industrial and structural applications, particularly in view of their tensile strength and yield point. Steel structures are constituted by the fabrication of structural steels in factories according to the project's specifications, followed by the assembly of these components on-site through various methodologies (e.g., welding, bolting, etc.) (Eren, 2014).

The fabrication and formability of steel is advantageous; it is more economical to produce than other alloyed metals and inorganic wood materials; steel construction is fast, design rules are few and simple, it has high mechanical properties such as tensile/impact strength, and it is weldable and corrosion resistant. Due to its numerous positive attributes, it is extensively utilised in construction, particularly in the United States (Williams, 2011).

The main reasons for choosing steel as a structural material can be listed as follows (Williams, 2011), (Schierle, 2006), (Chandrasekaran, 2020):

- Provides architectural freedom to design,
- Structural element dimensions can be quite small,
- Can be produced with a variety of properties to suit different requirements,

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- Flexibility of use,
- Durability and reliability,
- Easily and precisely produced,
- Steel components can be prefabricated off-site, which speeds up the construction process and reduces on-site labour costs.
- Steel is 100% recyclable, which makes it an environmentally friendly material in terms of sustainability.

Reinforced Concrete Structures

Reinforced concrete, which is obtained by mixing cement, water, aggregate and chemical additives homogeneously and is a combination of concrete that works under pressure and steel bars that work in tension, is the most used structural system today.

Advantages of reinforced concrete structures compared to wooden and steel structures can be listed as follows: (McKenzie, 2004), (Doğangün, 2021), (Schierle, 2006)

- Easy and economical construction,
- Eliminate combining structural elements,
- Easy and cheap maintenance
- Resistance to external factors such as freezing and corrosion,
- Prolongation of the economic life of the building,
- Possibility to give the building elements the desired shape and decorations, such as motives/paintings,
- High compressive-tensile strength,
- Post-tensioning and pre-tensioning construction methods facilitate the crossing of large openings.

Despite the advantages of reinforced concrete structures, their major weakness is that they are heavier than wood and steel structures. In the context of large-span reinforced concrete structures, an inverse relationship is observed between element size and the structure's economic advantage over steel. Specifically, as element size increases, the structure's overall weight increases concomitantly, thereby diminishing its cost-effectiveness in comparison to steel alternatives. Consequently, the seismic loads acting on the structure also increase. In the absence of prefabrication, reinforced concrete structures necessitate a greater investment of time than steel and wood structures in order to be constructed. Moreover, this construction method, which is implemented in a construction site environment, exhibits a high propensity for errors. In the event of irreparable defects, the demolition and rebuilding of the affected component may be necessary.

The dismantling and recycling of steel and wood structures is a well-established process which is frequently employed at the conclusion of their useful life. These materials can be reused in a variety of applications. In contrast, the same cannot be said for concrete materials, which are significantly less amenable to dismantling and recycling. Concrete is frequently utilised as a filler material in recycling, yet the process of rendering it suitable for this application is notably arduous.

The construction of a reinforced concrete structure necessitates the utilisation of formwork, which serves to hold the poured concrete in place until it sets. Additionally, scaffolding is employed to provide support. The cost of formwork constitutes a significant consideration in the context of reinforced concrete structures. In certain instances, the financial outlay pertaining to the materials and labour required for the

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implementation of formwork and scaffolding can account for nearly half of the total construction cost. The adoption of standardised dimensions for structural elements, in conjunction with the utilisation of highly reusable formwork, has been identified as a potential strategy for mitigating the adverse impact of this unfavourable scenario.

The significant margin of error inherent in the construction of the reinforced concrete structures necessitates the implementation of a high coefficient of safety in static calculations, consequently resulting in the utilisation of greater material quantities. This has a direct impact on the overall cost of construction. Another disadvantage associated with the reinforced concrete structures is the complexity of implementing and adding reinforcement.

Reinforced Concrete-Steel Composite Structures

Within the domain of construction, composite materials, structural elements, and structural systems are utilized in buildings in a variety of ways. As Designing Buildings (n.d.) asserts, composite materials offer a wide range of benefits.

- It is imperative to note that the product has been engineered to exhibit enhanced durability, making it particularly well-suited for utilisation in extreme environmental conditions.
- The object under consideration is of a lightweight composition.
- The primary benefit of this approach is that it results in reduced construction times.
- It is frequently possible to effect repairs to structures in situ.
- The property is notable for its low maintenance requirements.
- The material is distinguished by its plasticity with regard to colour, shape and texture.
- The material has the potential to be rendered fire-resistant.
- The object exhibits a high ratio of strength and stiffness to weight.

The term 'composite structural elements' include reinforced concrete columns cast in steel tubes, I-beams encased in concrete material, and concrete slabs cast on trapezoidal sheet metal. The primary benefit of the closed composite beam and column is to provide both fire resistance and corrosion protection. The primary benefit of the composite steel truss configuration is to facilitate the efficient passage of utility systems through the open gaps in the beamed ceiling. The utilisation of an Omega plate within the composite slab functions as a formwork for the concrete to be poured. A key disadvantage of composite slabs is the transmission of vibration between the gaps that can occur as a result of passing through a larger opening with smaller-sized elements (Williams, 2011).

In terms of structural performance, composite structures are defined as the appropriate combination of components made from different types of materials in a structure that carry critical loads. The utilisation of composite design has been demonstrated to engender substantial reductions in both financial expenditure and the duration of construction in a multitude of bridge and floor structures. The field of composite design and construction technologies has seen significant advancements in materials and methodologies, with continuous improvements being made (Narayanan, 2005).

The enhanced performance of composite structures can be attributed to the augmentation in strength and stiffness that can be accomplished through the effective utilisation of materials. When these two materials are employed in conjunction, their respective strengths can be leveraged to achieve a highly efficient and lightweight design. The reduced self-weight of composite elements exerts a secondary effect by reducing the forces in the elements that support them, including the foundations. The utilisation of composite construction renders the system resilient and obviates the necessity for precise tolerances, thereby

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facilitating expeditious construction. As demonstrated in Steel Construction (n.d.), the reduction in floor depth that can be achieved through the implementation of composite construction can also provide significant benefits in terms of the cost of services and the building envelope.

The profiled steel plate employed in the composite slab system is a cold-formed omega-profiled plate surface that functions as both formwork and tensile reinforcement for cast-in-place reinforced concrete slabs. The omega-profiled plate provides effective span penetration capability in the transverse direction and has an efficient two-way span penetration capability for slab laying. These connections can be welded to galvanized steel floors and steel joist floors safely and easily. It is imperative that the reinforced concrete and steel elements possess the capability to transfer shear forces to each other. The integration of welded studs within the system facilitates the collaborative functioning of concrete, tile, and steel components, thereby ensuring the system's capacity to resist dead loads. These studs have been welded to the steel members and are thus not removable. The process of concrete setting results in the formation of a bond between the steel and the concrete. In multi-storey buildings, the studs are typically welded to the load-bearing steel beams. This is followed by the installation of steel rings, which are then combined with other flooring systems (Ince et al., 2015).

A composite beam can be formed in the following ways (Samuelson, 2002), (Evans and Write, 2005), (Johnson, 1994), as shown in Figure 1:

1. A steel shape completely encased in concrete,
2. A flat soffit concrete slab cast on a steel shape with the slab connected to the steel shape with steel anchors,
3. In the form of a concrete slab poured over an omega plate, where steel anchors are used to connect the slab to the steel beam,
4. In the form of a concrete slab poured over an omega plate, where steel anchors are used to connect the slab to the steel truss.

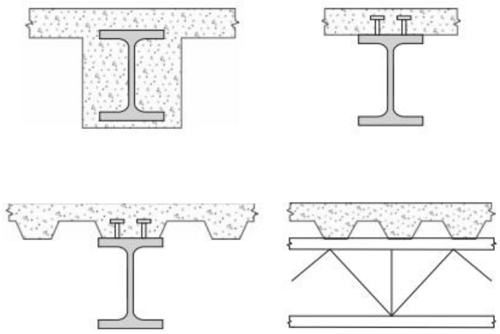

Figure 1. Composite beam types (Williams, 2011)

The systems obtained by combining structural steel and reinforced concrete systems and showing composite behaviour are as follows (Taranath, 2012):

1. Composite moment frames
2. Composite braced frames
3. Composite eccentrically braced frames
4. Composite shear wall-frame interactive systems
5. Composite tubular systems
6. Vertical mixed systems
7. Mega frames with super columns
8. High impact structures

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In the event of the correct implementation of combination techniques with regard to structural elements, edifices utilising composite elements (i.e. composite floors, composite beams, composite columns, composite diagonals and composite shear walls) will also demonstrate composite behaviour. The utilisation of composite structural elements within the load-bearing systems of buildings has been demonstrated to engender several key benefits. These include the extension of the building's economic life, the reduction of its weight and cross-section, and the enhancement of the reinforcement ratios of the structural elements. Moreover, the provision of sufficient ductility has been shown to minimise the rate of damage and material loss of the building under the effect of earthquakes (Elhasan, 2022).

Introduction of the New Atatürk Cultural Center Building

In 1956, the Ministry of Public Works commissioned the architect Hayati Tabanlıoğlu, who had completed a doctorate on theatre buildings in Germany, to design the Atatürk Cultural Centre, which was to be Türkiye's first opera house. The construction was completed in 1969, and the building was inaugurated as the Istanbul Palace of Culture (Figure 2.a). Following the fire, the building was restored by the architect Tabanlıoğlu and reopened for a second time in 1978 as the Istanbul Atatürk Cultural Center (AKM) (BBC News Turkish, n.d.). The Atatürk Cultural Centre was constructed on a site measuring 14,600m² within a larger plot of 31,000m² (see Figure 2.b). The building was composed of a 1300-seat Grand Hall, a 500-seat Concert Hall, a 300-seat Theatre Hall, a 200-seat Cinema Hall, a substantial Exhibition Hall, and a 190-seat 'Aziz Nesin Stage' which was added in 1993.The facades of the building, constructed on a reinforced concrete skeleton system, were prepared in accordance with the national architectural movement of the time (Hasol, n.d.).

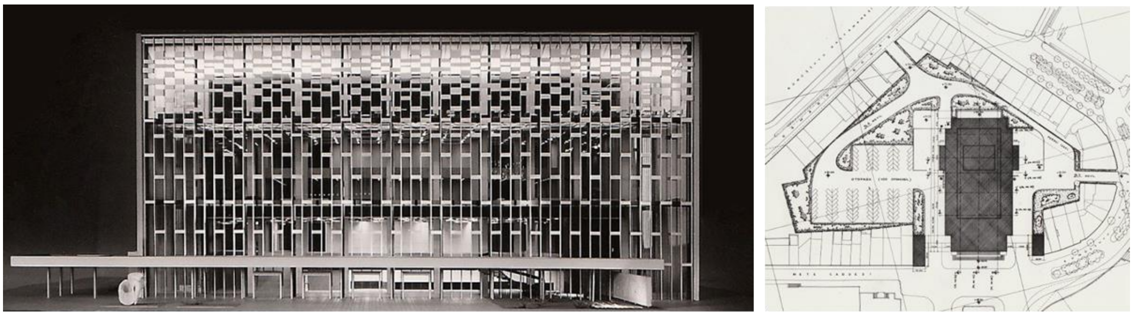

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Figure 2. (a) Atatürk Cultural Center; aluminium-steel façade made by Arçelik, 1957 (Salt Araştırma, n.d.), (b) AKM site plan (Salt Araştırma, n.d.)

On November 1, 1999, Istanbul Conservation Board No. 2 registered the AKM building as a Group 1 cultural asset. In 2005, the Minister of Culture and Tourism proposed demolishing it, claiming it was at the end of its economic life. On 31 May 2008, AKM closed for renovation, with the Tabanlıoğlu Architecture practice being commissioned to oversee the project. Then the building was demolished in March 2018 and subsequently rebuilt as the New AKM building, which was completed 32 months after the groundbreaking ceremony. The financial outlay was approximately TL 2.2 billion. The new building comprises a 2,400-seat opera hall, an 802-seat theatre, exhibition halls, a library with 20,000 books, a Yeşilçam cinema, a music recording studio, offices, restaurants, and cafes (BBC News Turkish, n.d.).

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Figure 3. (a) New AKM building layout plan (Akmistanbul, n.d.), (b) Bird's eye view of the new AKM building (Mimarizm, n.d.)

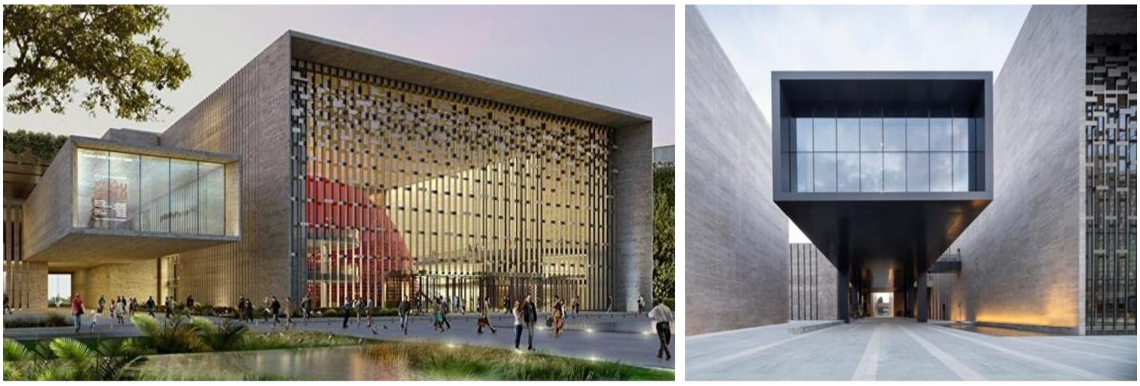

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Figure 4. (a) New AKM building model (Mimarizm, n.d.), (b) New AKM building Art Gallery view (Mimarizm, n.d.)

The architectural conception of the new Atatürk Cultural Centre was developed on the grounds of the original construction, which bears the same designation, in Taksim Square, with the construction process concluding in 2021 (see Figure 3.a-b). The primary mass of the new building (Block A) was retained in its original form, including its façade and gauge, as illustrated in Figure 4.a. In addition, smaller supplementary blocks were incorporated into the new building, each with distinct functional characteristics. As illustrated in Figure 4.b, the front view of the Art Gallery of Block B is presented. In the following discourse, the building will be designated as the ‘New AKM’ building.

The project is composed of five distinct components (Figure 5-6). Block A consists of an opera hall with a capacity of 2,500, in addition to restaurants and offices. Block B comprises a theatre hall with a capacity of 800, a chamber theatre with a capacity of 200, meeting rooms, design shops and an art gallery. Block C is equipped with a multi-purpose hall with a capacity of 500, two exhibition halls with a capacity of 250, meeting rooms, cafes, and shops. Block D houses three exhibition halls and a library. Block E contains restaurants and cafes.

The recently constructed AKM building, with a total area of 95,600m², is divided into two sections. An opera house with a capacity of 2,500 people was constructed on the site of the former AKM building, and the development also incorporated concert halls, theatres, exhibition rooms, rehearsal rooms, foyers, chamber theatres, libraries, cafes and restaurants, workshops and storage areas, and art galleries. These facilities were located in the section extending to the parking lot of the old building (Figure 6.a). The construction involved the use of 65,000 m3 of C40 class concrete, 11,000 tonnes of B420C class reinforcing

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steel, 3,650 tonnes of S235JR-S275JR and S355JR structural steel, and the total weight of the building was 165,000 tonnes. As illustrated in Figure 6.b, particularly beneath blocks B and C, there is a 4-storey basement with a floor height of 3.20 m, constructed with a beam slab and utilised as a car park. It is evident that the areas below the natural ground level in Blocks B, C, D and E, which are constructed with reinforced concrete cassette slab roofs, are almost equal to the areas above the natural ground level. The 5-block building is situated on a site that experiences a total height difference of 12 metres.

The A and B Block Art Gallery structures (Figure 4.b), which have a high proportion of structural steel and composite elements, are discussed in more detail below.

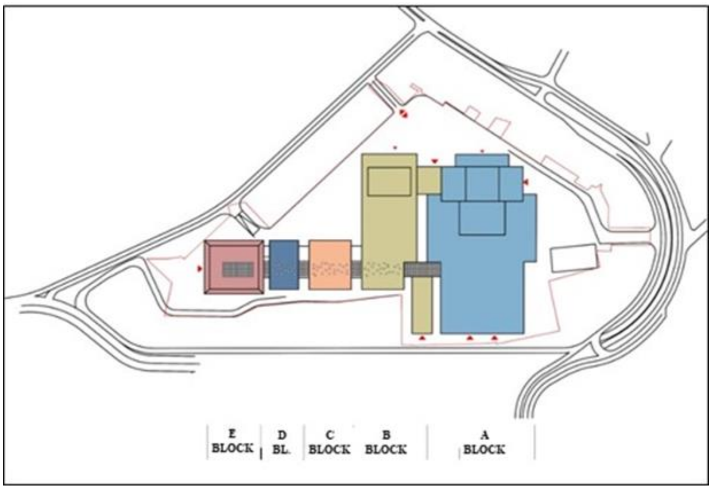

Figure 5. Block types of the building (Mimarizm, n.d.)

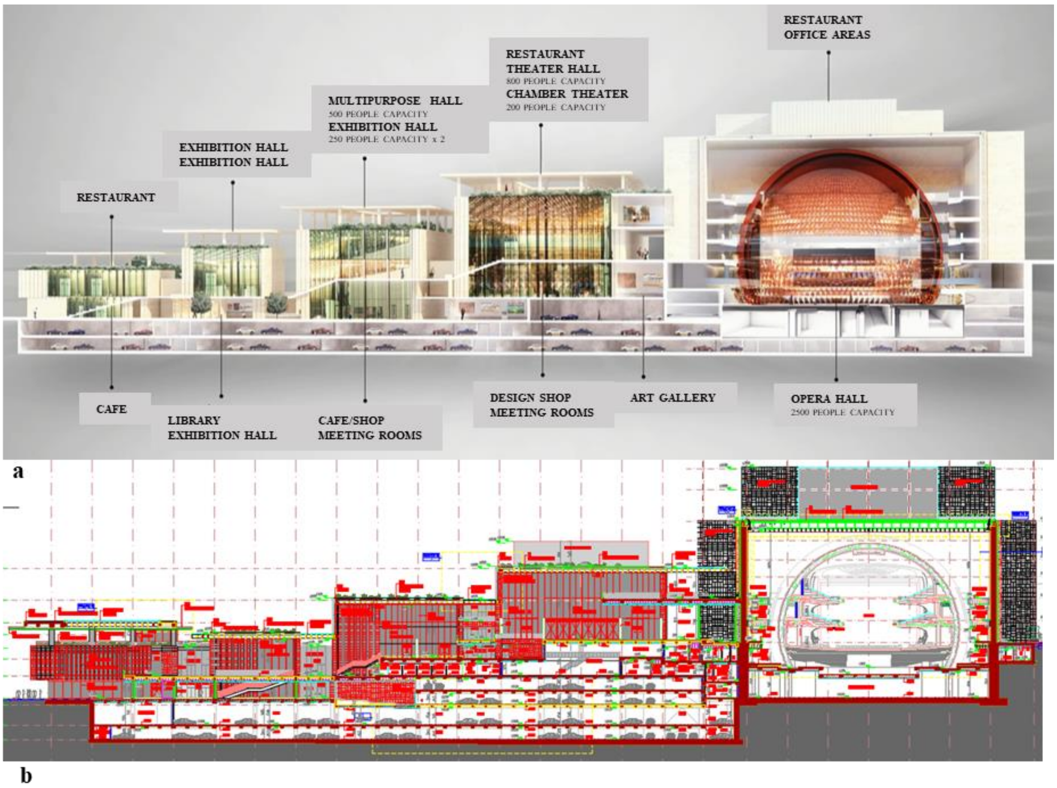

Figure 6. (a) Section showing the spatial layout of the New AKM building (General Directorate of Investment and Enterprises, n.d.), (b) Section drawing (Balioglu, 2019)

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A Block Presentation

Block A comprises reinforced concrete and steel structural systems. Despite the fact that this segment of the building is composed predominantly of reinforced concrete, particularly the hemispherical Opera Hall, which is supported by steel beams, it is founded upon reinforced concrete columns and a ribbed slab. This distinguishes it within Block A as an exemplar of reinforced concrete-steel composite systems (see Figure 7.a-b). As illustrated in Figure 7.a, Block A comprises a series of interconnected spaces, with the foyer floors surrounding the spherical form composed of composite slabs. Additionally, the roof of the sofita and the main hall are constructed with steel trusses, contributing to the structural integrity of the building. The stage slabs are spanned by post-tensioned reinforced concrete beam slabs, and the backstage areas with small openings are constructed using a reinforced concrete skeleton system. As illustrated in Figure 7.b, the upper floor plan of the primary structure outlines the configuration of the opera hall, the primary stage, secondary stages, the backstage areas, and the foyer. As illustrated in Figure 8, the ceramic-covered exterior of the Opera Hall and the entrance to the foyer area are clearly visible.

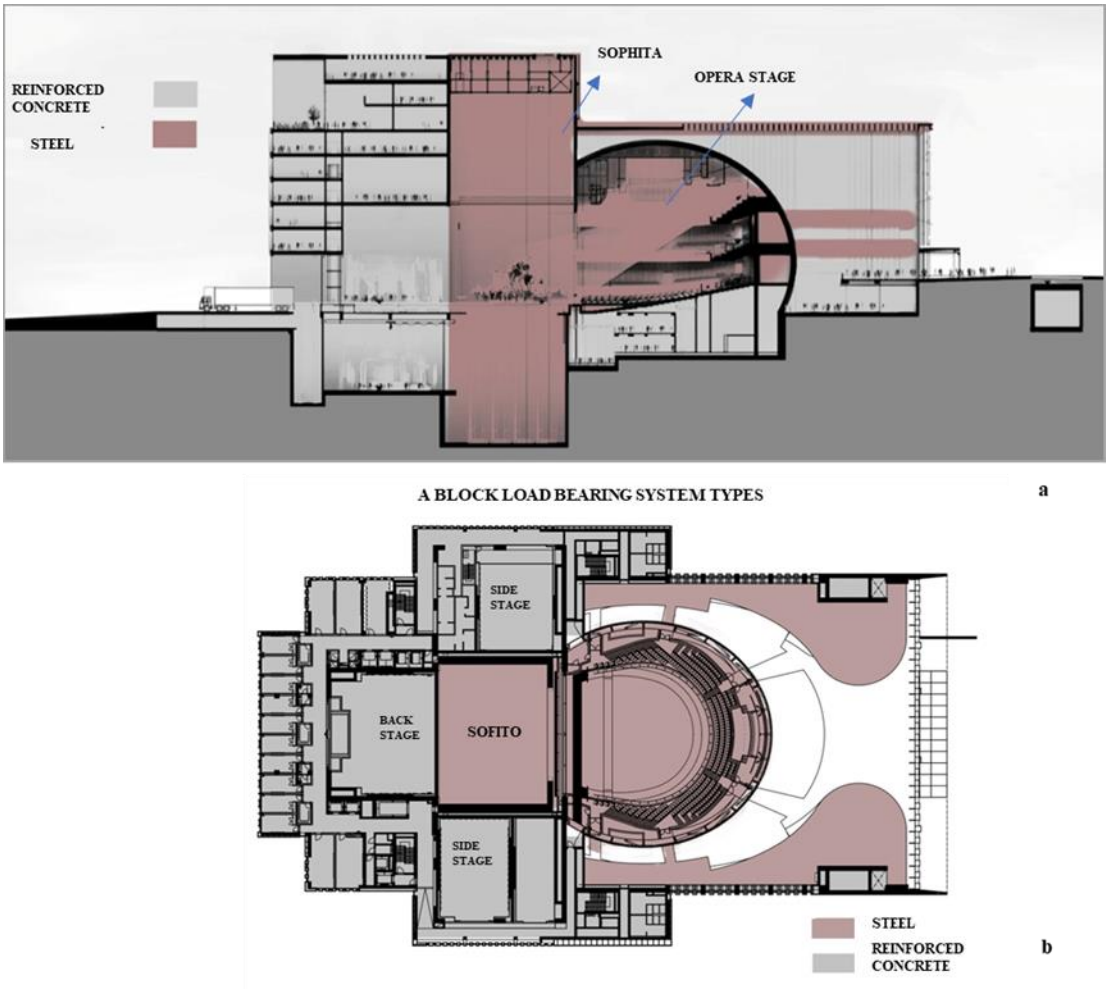

Figure 7. (a) Plan showing the structural system types of Block A (Balioğlu, 2019), (b) Section of Block A (Vimeo, n.d.)

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Figure 8. A view of the Opera Hall and its entrance (BBC News Turkish, n.d.)

The monumental, spherical facade of the Opera Hall, constituting the primary element of the architecture of the New AKM Building facing Taksim Square, was adorned with 15,000 meticulously designed and crafted ceramic pieces (see Figure 8.a-b). The Opera Hall, situated within the confines of Block A, was designed and constructed in the form of an ellipsoid with dimensions of 39.5 metres in diameter and 27.5 metres in height. The hall is equipped with a mezzanine and two balconies, and has a capacity of 2,040 spectators. The seating configuration ensures that there are suitable viewing angles for the audience from every point (Figure 7.a). The orchestra pit, measuring 125m², has the capacity to accommodate an ensemble of up to eighty-five musicians (BBC News Turkish, n.d.). In order to reduce the seismic loads as well as the weight of the structural system, and to facilitate formwork applications, it was preferable to use a steel system as opposed to reinforced concrete (see Figures 9a-b).

The sofita, which was located above the stage section and contained pulley systems, cranes, bridges, catwalks, fire and stage curtains, was designed as a steel structure (see Figure 7a). Figure 9.a demonstrates the structural design of the building, with a section through the Opera Hall in Block A providing a clear illustration. The opera hall and mezzanine floors were made of steel, while the building's foundation surrounding the opera hall and the basement floor ceiling were made of reinforced concrete. The 54-metre-span roof, supported by reinforced concrete shear walls, was crossed by flat steel trusses. The lobby roof was formed using 150 cm-high, 54 m-span and 6 m-spaced flat steel trusses. Ensuring coherence between the highest point of the roof and the existing building resulted in limitations on the height of the trusses and the highest point of the opera house's ellipsoidal design. If the truss heights were to exceed the optimum level, the ellipsoidal geometry of the opera house would be subject to compression. The limited truss height and large spans meant that HD (high wall thickness) steel sections had to be incorporated into the system (see Figures 9a and 9b). Figure 9.b illustrates an aerial photograph of the building's construction phase. Construction of the building, which was located in a confined space, was carried out using high-capacity telescopic mobile cranes.

Figure 10 shows the model perspective of Block A and the Art Gallery. In this view, the reinforced concrete elements are left white, while the steel ball, the reinforced concrete post-tensioned slabs and the roof steel trusses are shown in colour.

In the space where the main stage was located, there are rear, left and right-side stages. On various levels of these stages, rehearsal rooms, work areas, and offices are situated, which are vital functions of the cultural centre. The requirement for the absence of internal columns in the stage areas gave rise to the problem of the carriage of slabs with a width of approximately 22 m over these spaces. While it is possible to support slabs of this size using reinforced concrete and steel girder systems, the limited height of the building and the challenging nature of the area made this impractical for a reinforced concrete structure.

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Initially, the slab was designed in steel, but cost studies revealed that a prestressed system would be a more cost-effective solution (Kuzu, 2021). Consequently, the stage slabs of the Opera Hall, which exceed 18/22 metres in span, were constructed using post-tensioned beam slabs (Figures 10–11). The post-tensioning cables within the slab system were placed on 40/60 cm beams formed with 150 cm axial spacing, and the moment was balanced by creating a reverse load against the slab's loads (Figures 11a, b and c). Therefore, the moments in the reinforced concrete were reduced and the tensile stress minimised, forming a 396 m² area with a reinforced concrete slab system and ribbed beams. The mezzanine floor between the sofita side stage slabs was constructed using a reinforced concrete cassette slab system (Figure 12).

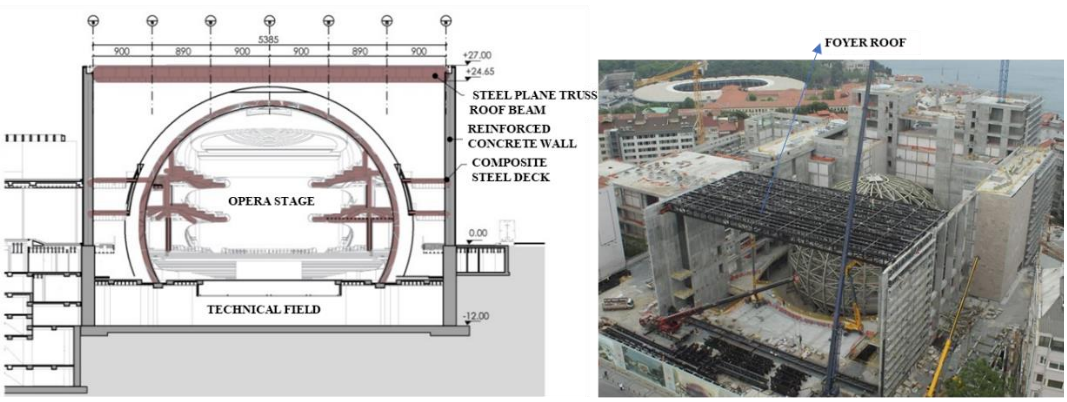

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Figure 9. (a) Foyer section (Balioğlu, 2019), (b) Foyer flat steel truss roof beams (TRT Haber, n.d.)

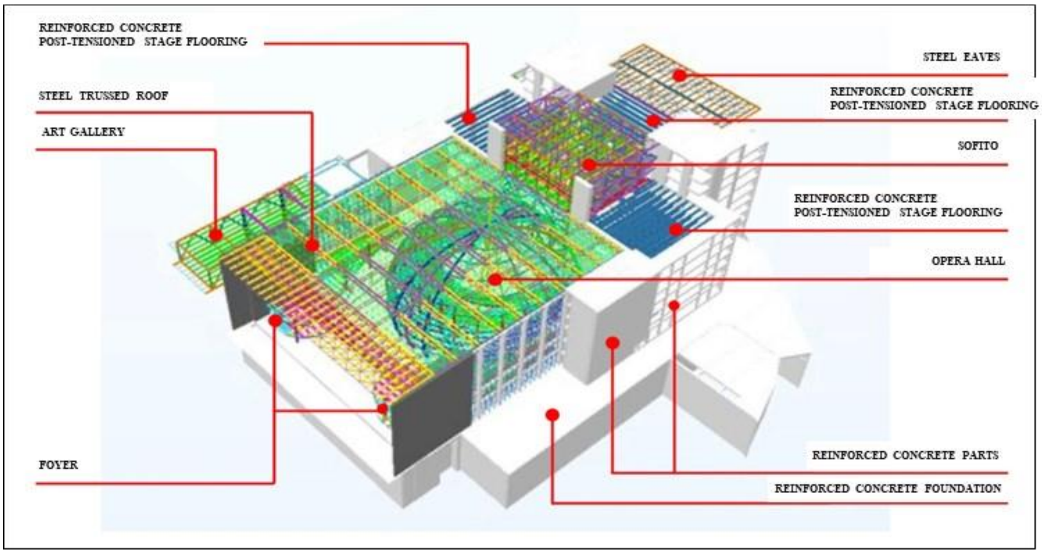

Figure 10. AKM Building, A block and Art Gallery steel and reinforced concrete parts (Balioğlu, 2019)

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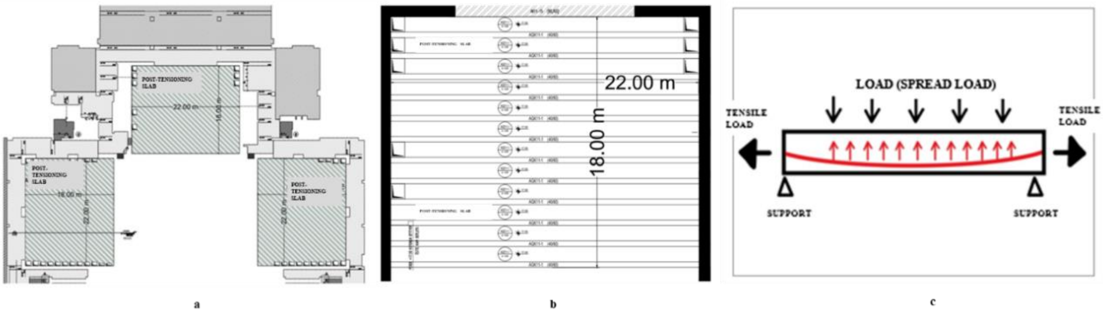

Figure 11. (a) Stage roof slabs made with post-tensioning method, (b) Mold plan of one of the 3 small stage slabs (Balioğlu, 2019), (c) Post-tensioning system diagram (Authors)

Figure 12. View from under the sofita (reinforced concrete cassette slab) towards the steel opera hall, construction phase (NTV, n.d.)

As shown in Figure 13.a (the formwork plan) and Figure 13.b (the photograph), there are two cantilevered foyer slabs that partially surround the opera hall from two sides. The structural systems of these sections are designed to be supported by a small number of columns. The minimum slab thicknesses and column sections have been used for these two-storey slabs (Figure 13.b). Steel structural systems are more suitable for structures with large spans and cantilevers. In these parts of the foyer area, the 6 m cantilevered slabs were therefore supported by steel frames and completed with 15 cm thick concrete and steel composite slabs (Kuzu, 2019).

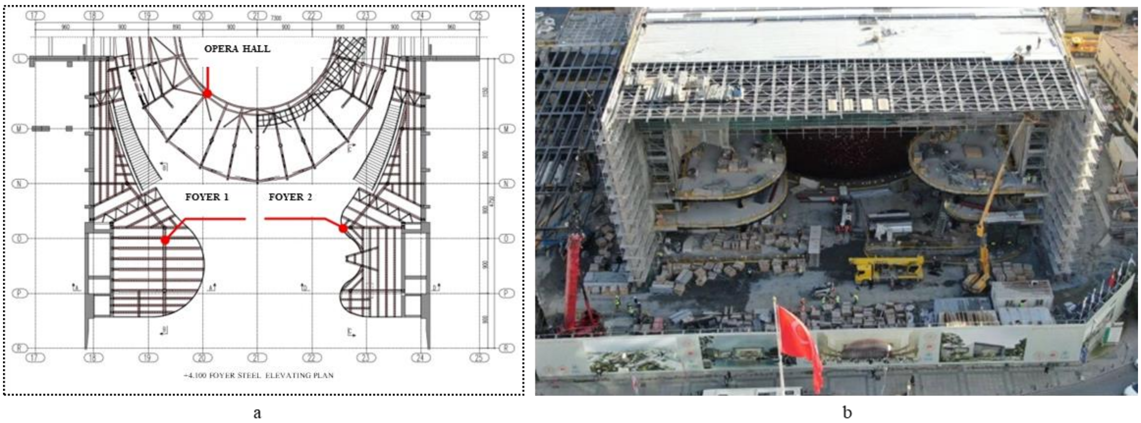

Figure 13. (a) Foyer area steel formwork plan (Balioğlu, 2019),
(b) A block foyer slabs and curtain walls construction phase (NTV, n.d.)

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B Block Art Gallery Presentation

The art gallery in Block B is a building with a cantilever length of approximately 18 metres (see Figure 14.a). Steel trusses were constructed at floor level (7 m) on both sides of this space to support a relatively wide-span cantilever (Figures 14.a and 14.b). The entrance to the Block B from the Taksim Square side is located beneath this cantilever (Figures 14.a and 15.a-b). It has a floor height of 10 metres and is accessed through two reinforced concrete curtain walls. This draws people to the pedestrian axis of the complex, which runs parallel to the square and continues through all the blocks. There are no additional columns within the space. Due to the specific cantilever structure, steel profiles were used for the horizontal and vertical structures in this section. The art gallery console is supported by four HI 120-20-60*600 steel section columns, which are placed at 12/18 metres on centre. These steel columns were set 350 cm deep in 245/120 cm concrete piers to support the system's stiffness.

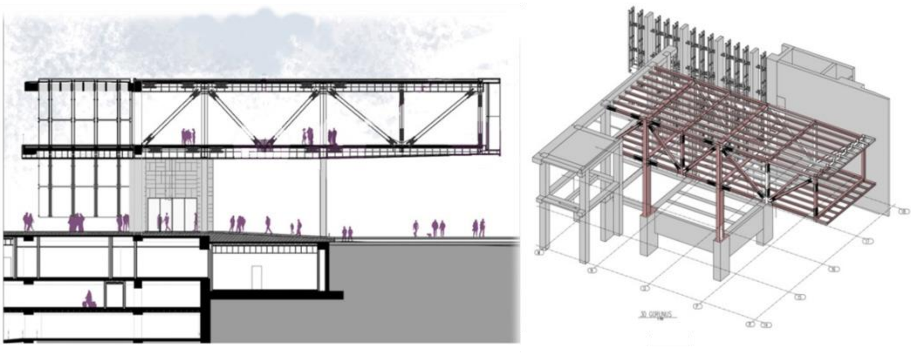

Figure 14. (a) Architectural section of the Art Gallery, (b) Perspective drawing of the steel and reinforced concrete systems of the Art Gallery (Balioğlu, 2019)

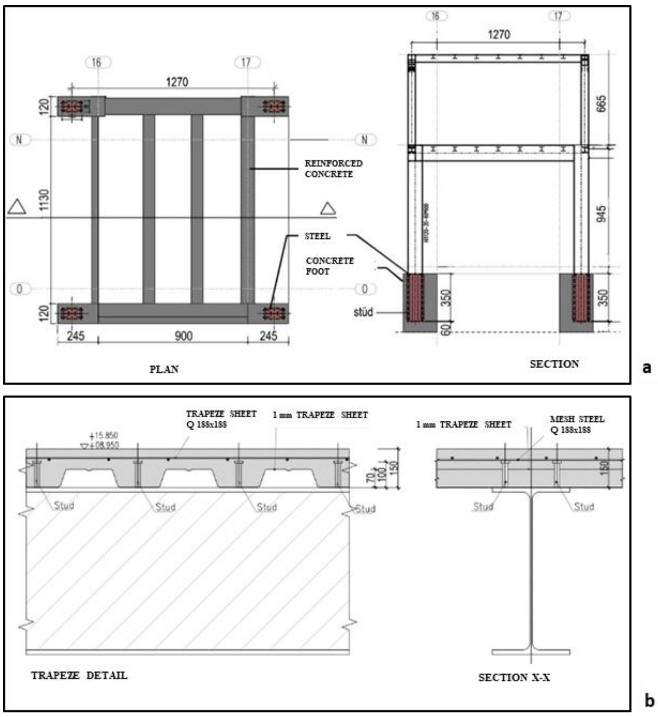

Figure 15. (a) Art gallery concrete-steel structural system relationship (Balioğlu, 2019), (b) Composite slab detail (Balioğlu, 2019)

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Evaluation of The New AKM Building

The possibilities and advantages of steel, reinforced concrete, and reinforced concrete + steel composite structural systems were evaluated in terms of ease of construction, strength, dimensions of the elements used, sustainability and cost (see Table 1). Table 2 shows how the same headings can be achieved in the New AKM Building and the AKM Building. The composite construction technique is widely used in many developed countries and is especially beneficial in regions and countries with high seismic activity, as it enables engineers to design the desired structures. The advantages of reinforced concrete-steel composite structures are listed below (Samuelson, 2002; Evans and Write, 2005; Johnson, 1994; Bedi and Dabby, 2020; İnce et al., 2015).

1. Reinforced concrete-steel composite structures are much lighter than traditional reinforced concrete structures. Therefore, in the event of an earthquake, there will be less structural damage with a lower earthquake load (see Table 1). At the Istanbul Museum of Modern Art (Figure 16), composite frames were used to support reinforced concrete columns for similar reasons. At Medeniyet University Library (Figure 17), the mezzanine floors above the entrance and the roof were constructed as composite slabs to reduce the building's load.

2. Reinforced concrete + steel composite structures can show more ductile behaviour against earthquake forces due to the use of more steel elements compared to reinforced concrete structures.

3. Since the steel structural elements in reinforced concrete-steel composite structures are fabricated in a workshop environment, the degree of quality control is higher than that of cast-in-place reinforced concrete systems.

4. Reinforced concrete-steel composite structures require 20% less steel than steel structures alone. A comparison of composite elements made from a combination of steel and reinforced concrete with structural systems made from either steel or reinforced concrete alone reveals that the ratio of the load they carry to their own weight is considerably higher.

5. In composite systems, the interface at the junction of parts made of different materials is very important because it directly affects the behaviour of the system. Damage caused by failed joints is the main problem and reduces the durability of the system.

6. Since the element sizes are smaller in steel structures compared to reinforced concrete ones, the overall building is lighter, which can lead to gains in usable floor area and floor height in the design. This advantage can also be achieved in concrete-steel composite structures (Table 1 and Table 2). Steel columns were used instead of reinforced concrete columns to create a larger open terrace area on the 2nd floor of the Medeniyet University Library (see Tables 1 and 2).

7. In cast-in-place reinforced concrete structures, it is not possible to construct additions; in steel and composite structures, it is easier to construct additions and connect the systems by assembling prefabricated steel elements on site.

8. The opera hall, with a capacity of 2,500, is surrounded by an ellipsoid shell measuring 39.5 metres in diameter and 27.5 metres in height. The height of the primary structure is 38 meters. In order to construct the shell within this height, it was necessary to utilise a steel structure with a wall thickness of 80 cm. Given the prestigious nature of the new AKM main building (A block), it was imperative to minimise construction errors. This necessitated the utilisation of a steel construction system for the shell.

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9. In their 2007 paper, Shamrani and Schierle conducted a comparative analysis of reinforced concrete frame, steel frame, reinforced concrete shear wall, and steel braced systems, evaluated in terms of material and workforce costs, across four distinct categories of story numbers. The study concluded that shear walls result in a 59% reduction in costs when compared to steel frame systems for 10-storey buildings. Furthermore, the study determined that the reinforced concrete frame system is the optimum structural system for 20, 30 and 40-storey buildings, with a cost reduction of between 66% and 69% when compared to steel frame systems. The study demonstrated that reinforced concrete frame systems exhibited the most economical use of materials and workforce across a wide range of structural systems, irrespective of the number of storeys. Nevertheless, the aforementioned benefits of composite structures render these systems more advantageous.

10. In order to circumvent the undesirable consequences of a thick and bulky reinforced concrete construction, a steel structure was employed in the art gallery section. This approach enabled the realisation of the desired architectural form, characterised by a minimal number of columns and a cantilever structure measuring 7 m in height and 18 m in length. This structural refinement, brought about by the incorporation of steel, has had a positive impact on the overall cost and construction time of the building. Analogous situations are evident in the foyer area (see Table 2).

11. The post-tensioning method applied to the rear and side stage slabs allowed the large openings in these sections to be crossed with a reinforced concrete system, and this part of the building to continue as reinforced concrete.

12. The roof of Block A, which can be considered as the main building and contains the opera hall and foyer areas, was crossed with steel trusses, which provided a solution to the challenging situation of the limited building height with a very thin cross-section compared to reinforced concrete.

Table 1. Evaluation table for reinforced concrete, steel, and reinforced concrete-steel composite frame structural systems (revised by the authors), (Johnson, 1994), (Doğangün, 2021), (Kuzu, 2021), (Shamrani and Schierle, 2007), (Abd EL-Tawab, 2018)

		STEEL SYSTEM	IN-SITU REINFORCED CONCRETE SYSTEM	STEEL +REINFORCED CONCRETE COMPOSITE SYSTEM
CONSTRUCTION	FORMWORK	Don’t need formwork	Requires formwork	Generally don't need formwork
	ASSEMBLY TIME	Quick assembly	Requires time for needed strength	Quick assembly
	LARGE SPANNING	Ability to pass through large spans	Ability to pass large spans with post-tensioning and pre-tensioning construction methods	Ability to pass through large spans (large openings can be crossed with smaller and fewer elements)
STRENGTH	STRENGTH	Has high tensile strength	Providing both tensile and compressive strength	The advantage of using two different materials together
	RESISTANCE	It is not resistant to external influences and has a high probability of corrosion	It has good fire resistance	Weak fire resistance of steel parts
DIMENSIONS	DIMENSIONS OF ELEMENTS	Small element sizes	Large element sizes	Reduction of carrier element size thanks to the use of steel elements
	STRUCTURE WEIGHT	Light weight of the structure due to the lightness of its elements	Too much building weight	Reducing the weight of the structure by using steel elements in the carrier system, a low building weight may mean that the earthquake load acting on the building will be low.
	BEAM/FLOOR HEIGHT	Low beam height reduces the building height	Increase in section height when crossing large spans	Reduction of floor section heights by using steel beams

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SUSTAINABILITY	RECYLING	Being recyclable	Does not allow much recycling	Steel elements can be recycled, reinforced concrete parts are also recycled nowadays, but it consumes a lot of energy
	PROJECT GROWTH	Providing the opportunity to grow in the future	Itis not possible to enlarge the buildings made with in- situ casting systems in the future.	Providing the opportunity to grow in the future
COST		Providing the opportunity to grow in the future	Itis not possible to enlarge the buildings made with in- situ casting systems in the future.	There may be an increase in cost due to steel elements

Table 2. Evaluation of old and New AKM buildings (authors), (Balioğlu, 2019), (Kuzu, 2021), (Arkitektuel, n.d.), (BBC News Turkish, n.d.), (Hasol, n.d.)

		NEW AKM BUILDING CONSTRUCTION SYSTEMS	DATA FOR THE NEW AKM	DATA FOR THE AKM
		RC-STEEL COMPOSITE SYSTEM		REINFORCED CONCRETE FRAME SYSTEM
CONSTRUCTION	FORMWORK	By using steel load-bearing systems in the art gallery, opera hall and foyer areas, and steel + concrete composite slabs in the flooring parts, the need for formwork has been eliminated.	Foundations, ground level floors, stage roofs and shear walls need formwork	Except walls all building structural elements need formwork
	ASSEMBLY TIME	Since the composite system is used, the manufacturing time is reduced.	32 months (February 2019–September 2021)	10-13 years (Foundation was constructed in 1956, but construction was cancelled, the 1960 coup halted construction for 3 years), (1956-1969)
	LARGE SPANNING	1) Large spannings were made with a steel system in the art gallery structure 2) 22m distance is passed with the reinforced concrete post-tensioning elements at the stage roofs.	22m stage floors are passed with rc post tensioning beams, 18m cantilever floor is passed with steel frame system, 56m roof floor is passed with 150cm high of plain truss beams	The roof of the main hall with a span of 24x27m is crossed with 3m high steel trusses, 10m span foyer floors are crossed with reinforced concrete beam floors.
STRENGTH	STRENGTH	Since there are parts of building where steel load-bearing systems are used, the total building load has been reduced.		
	RESISTANCE	Since the total building load has been reduced, earthquake resistance has been contributed.		
DIMENSIONS	DEMINSIONS OF ELEMENTS	Due to the need to preserve the height of the old building, the shell system of the opera hall was created using steel profiles and the internal volume of the hall was expanded.	Rein forced concrete column dimensions; 80x80cm, 50x50cm, Curtain wall dimensions; 50x150cm, 100x200cm, 50x200cm, Beam dimensions; 40x60cm, Slab thickness; 20cm, Steel columns; 40x42cm, Steel beams; 40x42 cm, 30x30cm, Steel columns; 60x112cm, 30x70cm	RC columns; 60x60,60x100, RC beams; 40x100, 30x70
	STRUCTURE WEIGHT	Reinforced concrete post-tensioning method, composite slabs and steel truss systems were used in large cantilevered slabs, foyer and stage slabs and roof slabs to reduce the building weight.		
	BEAM/FLOOR HEIGHT	In the foyer areas, less floor sections were obtained by using steel flooring system.	Art gallery; 40cm/7m, Foyer; 55 cm/3.5m-7m	70cm/4m
SUSTAINABILITY	RECYLING	The extensive us e of steel material in the structure allows for recycling in the future.	Steel materials are recycled at a rate of 90% and reinforced concrete can be recycled and reused as gravel and blockage	The concrete materials from the demolition of the old AKM building, which was built as a reinforced concrete skeleton system, were recycled as ravel, and reinforcement materials were recycled as scrap. The trusses above the main hall were also transformed.
	PROJECT GROWTH	Since this project is located in a limited area, it is not possible to expand the project horizontally and vertically in the future.	x	x
COST		Fast assembly was made with steel elements; thus the construction site process was accelerated, and labor costs were reduced.	2.2 billion TL (as 2019)	85 million TL (as 1969)
TOTAL PROJECT AREA			95,600 m²	14,600 m²

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13. In the course of the construction of this new building, the objective has been to preserve the facade and openness of the old AKM building. However, the interior space has been designed to be slightly more spacious and to feature continuous, lighter elements in comparison to the old building. In this structure, which was erected in Istanbul, a seismic city, a steel frame system was employed in conjunction with the reinforced concrete system. The implementation of a steel frame system not only enabled the creation of substantial apertures but also served to reduce the load on the structural system. In this respect, the purpose of the steel system at Medeniyet University Library is analogous. The New AKM Building and other structures previously referenced were constructed using reinforced concrete due to its capacity to resist seismic activity and offer protection against the risk of fire, a matter of paramount importance in buildings intended for public use.

Examples of composite buildings constructed at the same time as the New AKM building include the Istanbul Museum of Modern Arts and the Istanbul Medeniyet University Library. The construction of both buildings incorporated the utilisation of reinforced concrete-steel composite slabs and structural steel elements. The Istanbul Modern building, constructed between 2016 and 2023, encompasses an area of 10,500 m² and comprises exhibition halls, multipurpose spaces, offices, and educational and cultural activity spaces distributed across five floors. The building is founded on reinforced concrete columns supported by steel with axes measuring 8.4x8.4m. The structure is composed of steel, concrete, and glass, and its architectural style aligns with the industrial character of the adjacent warehouses (Şantiye Edergi, n.d.a).

In order to ensure cost-effectiveness in the structural system of the building, the cast-in-place reinforced concrete skeleton system, which is a common construction method in the local area, was utilised. The structural system, consisting of reinforced concrete columns, beams, and slabs on a reinforced concrete foundation, is supported by composite frames against earthquakes due to the high-risk location of the project. The system has been designed to undergo plastic deformation during an earthquake, as evidenced by its conceptualisation as a 'high ductility central braced frame'. In this system, known as 'capacity design' in the field of engineering, the central regions of the frames undergo plastic deformation through buckling under compressive loads triggered by seismic activity. The connections are engineered to enable the crosses near the glass and other partitions to deform in the direction of their vertical axes, thereby preventing the crosses from damaging the partitions under the earthquake effect and ensuring the partitions do not suffer damage from the earthquake (see Figure 16) (Şantiye Edergi, n.d.a).

Figure 16. Istanbul Museum of Modern Arts (Arkitera, n.d.)

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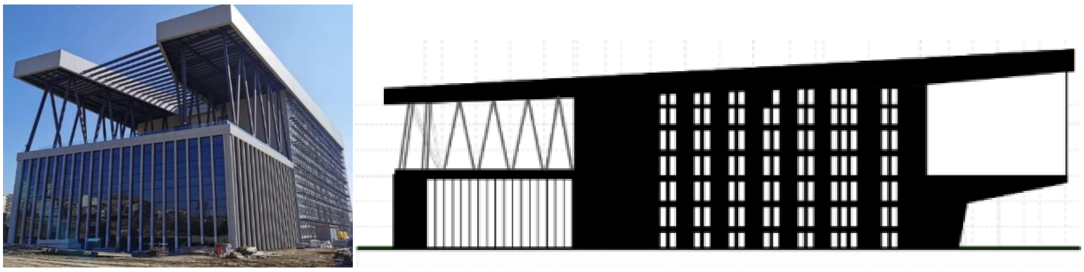

Figure 17. İstanbul Medeniyet University Library Building, left; rear perspective view, 2020 (Sistem Alüminyum, n.d.), right; north-east facade of the building (Topatan, 2021)

The Medeniyet University Library building, located within the Göztepe campus of Medeniyet University, was constructed between December 2018 and August 2020 (Figure 17) (Şantiye Edergi, n.d.b). The total construction area of the building is 28,000 m², and the construction costs amounted to 93 million TL (Şantiye Edergi, n.d.b). The primary structural system of the building is a reinforced concrete frame system (average column axis 7x7m, columns 80x80cm, beams 40x60cm). In order to facilitate the establishment of openings measuring up to 15 m in the intermediate floors of the entrance section without placing excessive load upon the reinforced concrete system, a reinforced concrete-steel composite floor system was utilised in the sloping roof slab. In the terrace area at the rear of the building, 'V'-shaped steel columns were placed to support a pair of eaves that extend 33 metres as a continuation of the roof. Given the requirement for spaciousness and openness in this area, the preference was for slender steel columns rather than thick cross-sectioned reinforced concrete columns, which require more frequent placement (Otman, 2025). The total construction area of the New AKM building is approximately three times that of the Medeniyet University Library building (95,600 m²/28,000 m²). The construction time for the library was 22 months; the New AKM was completed in 32 months.

Table 3. Types of structural systems of AKM Building A and B blocks and the benefits they provide (Authors)

NEW AKM BUILDING A-B BLOCKS							ADVANTAGES							
	REINFORCED CONCRETE FOUNDATION	REINFORCED CONCRETE LOAD-BEARING SYSTEM	STEEL FRAME SYSTEM	REINFORCED CONCRETE FLOORS	COMPOSITE FLOORS	STEEL FLOORS	Lightness of Structure	Construction Time	Construction Cost	Without Formwork Production	Reduction in Building Section Height	Earthquake Resistances	Construction Quality	Labor Gain
OPERA HALL	*		*	*		*	✓	✓		✓	✓	✓	✓	✓
ART GALLERY	*		*		*		✓	✓		✓	✓	✓	✓	✓
FOYER	*	*	*		*	*	✓	✓	✓		✓	✓	✓	✓
SOPHITA	*	*	*			*	✓	✓	✓	✓	✓	✓	✓	✓
SIDE STAGE AND WORK AREAS	*	*		*					✓			✓		

Table 3 shows the steel and reinforced concrete structural elements that comprise Blocks A and B of the New AKM Building, as well as the contribution of these structural choices to the building itself. The Opera House is a steel structure resting on reinforced concrete foundations and slabs. Its prefabricated construction, which eliminated the need for formwork, delivered consistent element dimensions and reduced manpower requirements throughout the construction process. The Art Gallery is also a steel

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structure with composite slabs resting on reinforced concrete foundations and columns. This structure has significantly reduced the overall construction time, decreased the building load, and lowered labour and formwork costs. The foyer, soffit and side stages have reinforced concrete foundations and columns, as well as steel and pre-stressed reinforced concrete slabs. These features increase the building's earthquake resistance and construction quality. Although the steel structures increased the material cost, they contributed to reducing the total cost in terms of compliance with construction speed and height limits. In-situ reinforced concrete is the technology with the longest construction time due to the time taken for formwork installation and removal and for the concrete to set. Steel systems, on the other hand, have the shortest construction time because they are fabricated in workshops and assembled on site, meaning the structure can be used immediately In their article comparing construction technologies in terms of various factors, Esirgen and Gültekin (2005) found that steel and reinforced concrete frame structures have a construction time difference of almost twofold. Steel-reinforced concrete composite systems have a construction time that falls between these two technologies.

A summary of the cost calculation for the new AKM building is presented in Table 4. The m² unit area cost method is used here. The total area of the new AKM building is 95,600 m², and the Ministry announced the total cost as 2.2 billion TL. Approximately two-thirds of the building's structure is made of reinforced concrete, while the remaining third is made of steel (Balioğlu, 2019). Had the building been constructed using only reinforced concrete and steel systems, the cost of the reinforced concrete system would have been around 223,000,000 TL and the steel system around 276,300,000 TL at 2019 m² prices. The composite system is therefore 8.3% more expensive than the reinforced concrete system, but 12.6% cheaper than the steel system.

The Construction of the Elbphilharmonie Hamburg Concert Hall took place between 2007 and 2014. Built around the same time as the new AKM, it has a construction area of 125,000 m² and was constructed using cast-in-place reinforced concrete columns, beams and shear walls, as well as precast concrete and steel frames for the roof and large openings. The Hamburg Philharmonic building is the most recent construction with which to compare the AKM's construction costs. It cost 875 million euros and took approximately 7.5 years to complete. The AKM cost 200 million euros, including technical components, and was completed in 2.5 years (Munyar, 2021). The difficult location of the Hamburg building, as well as the fact that it was built on an old foundation, caused the cost to increase. However, the new AKM building was constructed in a much shorter timeframe at a lower cost. While the cost per square metre of the Elbphilharmonie Hamburg concert hall was €7,000, the New AKM building was realised at €2,072 per square metre.

Table 5 shows the results of a structural weight study for Blocks A and B, which were constructed as a composite system. The table shows the current material weights of concrete, reinforcement and steel. The table also shows how the weight of the building's load-bearing system would change if these blocks were constructed using only reinforced concrete or structural steel. The reinforced concrete foundation for the steel is disregarded here. It is assumed that the structural steel used to construct the buildings is 60% lighter than reinforced concrete (Oehler and Bradford, 1995). According to the results, Block A would be 4.4% heavier than the current building if constructed with only a reinforced concrete frame system and 58.2% lighter if constructed with only structural steel. Block B would be 3% heavier than the current building with a reinforced concrete frame system, and 58.8% lighter with structural steel. Although the weight loss gained by the composite system compared to reinforced concrete seems small, this is because the structural steel used in the blocks is proportionately small (0.3% of the building dimensions).

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Table 4. Cost calculation schedule for the structural system of the New AKM building (Authors)

			New AKM Building Cost Calculation (for 2019)
Surface of Construction Area	**Steel Frame System**	**Reinforced Concrete Frame System**	**Reinforced-Steel Composite System; steel-1/3 of total construction area, reinforced concrete – 2/3 of total construction area**
95,600 m^2	Average cost per m^2 for Cinema – Teather Buildings made with first class quality which have Steel Frame Load-Bearing System	Average cost per m^2 Cinema – Teather Buildings made with first class quality which have RC Frame Load – Bearing System	
	2,890 TL per m^2 (for 2019) (Insapedia, n.d.)	2,330 TL per m^2 (for 2019) (Insapedia, n.d.)	
	95,600m^2x2,890TL=2746,300,000TL	95,600m^2x2,330TL= 223,000,000TL	31,600m^2 Steel Frame Systemx2,890 TL 64,000m^2RC Frame Systemx2,330 TL
			150,000,000 TL + 91,400,000 TL
TOTAL COST OF STRUCTURAL SYSTEM	**276,300,000 TL**	**223,000,000 TL**	**241,400,000 TL**

Table 5. Table for the study of the weight of the structural system for the A and B blocks of the New AKM building (Authors)

Weight of New AKM	**165,000 tonne**			
Block A (composite system)	Amount of Concrete	35,000m^3=77,000 tonne	85,600 tonne	
	Amount of Reinforcement	6,100 tonne		
	Amount of Structural Steel	2,500 tonne		
Block A (if it was built with only reinforced concrete system)	Amount of Concrete	35,000m^3=77,000 tonne	89,350 tonne	%4 more heavier
	Amount of Reinforcement	6,100 tonne		
	Reinforced Concrete Instead of Structural Steel	2,500x2,5=6,250 tonne		
Block A (if it was built with only structural steel system)	Structural Steel Instead of Reinforced Concrete	(77.000+6,100)x0.4= 33,240 tonne	33,240 tonne	%58.2 more lighter
	Structural Steel	2,500 tonne		
Block B (composite system)	Amount of Concrete	24,500m^3= 53,900 tonne	59,020 tonne	
	Amount of Reinforcement	4,000 tonne		
	Amount of Structural Steel	1,120 tonne		
Block B (if it was built with only reinforced concrete system)	Amount of Concrete	24,500m^3=53,900 tonne	60,750 tonne	%3 more heavier
	Amount of Reinforcement	4,000 tonne		
	Reinforced Concrete Instead of Structural Steel	1,120x2,5=2,800 tonne		
Block A (if it was built with only structural steel system)	Structural Steel Instead of Reinforced Concrete	(53,900+4,000)x0,4 23,160 tonne	24,280 tonne	%58.8 more lighter
	Structural Steel	1,120 tonne		

CONCLUSION

Composite structures, formed by combining steel and reinforced concrete systems, offer advantages over the use of these materials alone by combining their positive aspects. Following the demolition of the original AKM building, which was constructed using a reinforced concrete skeleton system, the new AKM building was constructed using a reinforced concrete skeleton system in addition to steel and composite elements. Block A required 35,000 m^3 of concrete, 6,100 tonnes of reinforcing steel, and 2,500 tonnes of structural steel. Block B required 24,500 m^3 of concrete, 4,000 tonnes of reinforcing steel, and 1,120 tonnes of structural steel. Very little structural steel was used in the smaller, lower Blocks C, D and E, only in the façades and roof skylights. Block A, which has a height of 51 m including the soffit and a floor area of 68 x 540 m, accounts for 85,600 tonnes of the 165,000-tonne complex's total weight. The other blocks, which have an average height of 26.5 m and more underground levels, weigh 79,400 tonnes. Block A's weight is inevitable given its steel Opera Hall, steel truss roof slab, composite mezzanine floors, reinforced concrete backstage units and pre-stressed side stage slabs.

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This study comparatively evaluated reinforced concrete-steel composite systems with reinforced concrete and steel frame systems, revealing their differences. In this context, the ease and time of construction, lightness, earthquake resistance, function and space utilisation of reinforced concrete-steel composite systems were compared with those of reinforced concrete and steel frame systems through the example of the New AKM Building. The following conclusions were drawn from a review of the literature and an evaluation of the results.

- In the contemporary context, reinforced concrete construction has attained a significantly higher level of prevalence in comparison to other systems. This can be attributed to the presence of a substantial number of trained technical teams and workers, as well as its relatively lower cost. However, the structural advantages of reinforced concrete-steel composite systems, such as greater seismic safety due to their lightness and ductility and more economical construction on soils with low bearing capacity, should not be overlooked. Despite the stability of the foundation of the new AKM building, the structure it replaces presented a height-related challenge that had to be addressed. Consequently, the 2,040-seat Opera Hall in Block A was constructed using structural steel. In order to eliminate formwork and reduce the weight of the building, the 39.5 metre diameter, 27.5 metre high auditorium was constructed in a flattened ellipsoid shape with steel trusses consisting of HEB700 ribbed ellipsoid columns and steel trusses with HEB600-300-200 elements resting on 80 x 80 cm reinforced concrete columns. The structure, which would have weighed 89,350 tonnes had it been constructed entirely in reinforced concrete, was constructed using structural steel for 85,600 tonnes, achieving a weight reduction of 4.4%.

- In this type of composite system, the structural use of steel materials enables the creation of slabs with thinner cross-sections and wider spans, thus allowing for higher floor heights, particularly in cases where the height of the building is limited. The construction of the New AKM building, which was subject to a height limit of 38 metres, required the utilisation of steel materials in a structural capacity. This facilitated the creation of cantilevered slabs with a thinner section measuring 55 centimetres in thickness and a length of 6 metres. This configuration enables the more efficient and precise construction of structural components of various geometric shapes, which are challenging to construct using reinforced concrete, such as the ellipsoid shell of the Opera House.

- In composite systems consisting of concrete and steel, the low fire resistance of the steel material is a negative situation. This disadvantage can be overcome by protecting the steel by covering it with fire-resistant concrete material. The steel components of the building, which are not concealed by concrete due to the system's design, are also fortified with fire-resistant decorative materials. In the new AKM, the steel elements of the building are covered with ceramic tiles, adobe panels, and composite wood panels.

- Notwithstanding the fact that steel, which is more expensive than concrete in terms of material cost, results in an increase in construction costs, it possesses several advantages. These include the potential for time savings, which is a valuable commodity in the present day, the reduction of labour costs, and the minimisation of returns due to labour errors and concrete element breakage. Given its status as a high-traffic and densely populated area, the New AKM Building was constructed in a location characterised by constrained spatial parameters and challenging accessibility, further compounded by the logistical intricacies of its utilisation. However, the fact that the steel truss elements were prepared in the factory and assembled at the site accelerated and facilitated the construction phase, and a construction of this magnitude was completed in 32 months. The Hamburg Philharmonic, with its floor area of 125,000m2, construction system and function, is the closest example to the New AKM. The construction of this building was estimated to cost €875 million, which is almost 3.3 times the cost of the New AKM, which was approximately €200 million.

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In this study, the structural introduction of A and B blocks of the New AKM building is presented, along with an explanation of their structural systems. A similar approach was adopted in the construction of the New AKM building, where a reinforced concrete skeleton system was utilised for its foundation and structural system in general. A comparable method was employed in the construction of the Istanbul Modern and the Medeniyet University Library buildings, which were constructed in the city in the last 15-20 years. These buildings also make use of steel structural elements in conjunction with a reinforced concrete skeleton system. The present study provides an explanation and comparison of the reasons for the use of the structural system known as reinforced concrete-steel composite systems in buildings of special architecture, with reinforced concrete and steel systems. In subsequent studies, the data regarding the operational periods of reinforced concrete-steel composite systems, the operating/maintenance-repair costs incurred, the potential issues that may arise during the utilisation of the building, and the structural system's contribution to space utilisation can be investigated through the conduction of user surveys. Numerical calculations can then be employed to facilitate the evaluation process.

Author Contribution Rate

Order	Name Surname	ORCID	Contribution to Writing*
1	Berrin ŞAHİN DİRİ	0009-0009-6436-2549	1, 2, 3, 4, 5
2	Erdinç BEKAR	0000-0001-5578-9625	1, 2, 4
* Write the number(s) corresponding to the relevant explanation in the contribution section.			
1. Designing the study 2. Collecting the data 3. Analysis and interpretation of the data 4. Writing the article 5. Critical revision			

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Conflict of Interest Statement

There is no personal and/or financial conflict of interest within the scope of the study.

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BIOGRAPHY OF THE AUTHOR

Berrin ŞAHİN DİRİ

She earned her bachelor's in architecture from Mimar Sinan University (1994) and completed her master's on tunnel formwork technologies (1997). Appointed as Research Assistant in 1995, she received her PhD in 2001 on shopping centres and became Assistant Professor in 2002 in the Department of Building Technology.

Erdinç BEKAR

He enrolled at Yıldız Technical University Architecture Faculty in 1990 and completed his bachelor's degree in architecture in 1995. In 2023, he obtained his master's degree from Mimar Sinan Fine Arts University with a thesis titled 'Examination of Long-Span Floor Systems with Examples.' Following his graduation, he has been working in the private sector as an architect.