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A Review on the Technical Design Considerations of Indoor Suspended Ceilings

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A B S T R A C T

The research aims to identify the technical foundations and considerations of designing suspended ceilings such as acoustic and fire performance. In particular, the research seeks to answer a critical question: What are the design considerations and evaluation criteria of suspended ceilings? Additionally, the research presents a comprehensive review of the performance of suspended ceilings and proposes a detailed set of design considerations for such ceilings.

The research focuses on studying the indoor suspended ceiling in the Middle East, as there are considerable design limitations in this region such as its arid environment. Despite the improvement of the design outputs during the last decade, there are still many shortcomings in the design of suspended ceilings that limits the solutions that meet the spatial needs of many buildings.

The research has three sections: The first section investigates how architects tend to design suspended ceilings; The second section examines the typologies of suspended ceilings; Finally, the third section presents the standards for designing modular ceilings provided by international codes.

1. Introduction

Each architectural space has its own technical design aspects such as acoustic performance, moisture resistance, preventing the spread of bacteria, air quality, and light reflectance.

Because of the diversity of the characteristics and capabilities of suspended ceilings and the different spatial needs, due to the ongoing evolution in the design processes for suspended ceilings, designers must keep updated on both the latest technological developments and the technical aspects of the suspended ceiling within the design process of their projects.

Recently, designers such as Frank Gehry, and Zaha Hadid have innovative forms and functionality that can have complex forms with effective use of materials following the common design aspects and considerations of false ceilings, such as the ceiling of Riverside Museum designed by Zaha Hadid.

The materials of such ceilings such as mineral fiber, wood, metal, and plastics, depend on the repetitive unit and textures. despite their modularity, such ceilings can offer infinite formations by understanding their nature [25], which can allow mass customization instead of mass production and deliver innovative ceiling alternatives.

To create innovative solutions for suspended ceilings that rely on modular components, the designers should understand the characteristics of these ceilings to understand their possibilities and limitations. Additionally, the designer should understand the technical design considerations of these ceilings to propose realistic, functional, durable, and reliable solutions.

Therefore, this research provides a review that

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can be helpful for the designers to understand the nature of suspended ceilings and their characteristics. The research starts with an investigation of how the architects design suspended ceilings. Then the research examines the typologies of suspended ceilings. And finally, The research presents the standards for designing modular ceilings provided by international codes.

2. Problem definition

Over the last decades, The Distinctive Parametric Ceilings, Which Are Parametric Achievement, Business, Architectural Engineering, Architects, and Architectural Elements. The construction of the building from the construction of the architectural construction of parametric architectural ceiling using architectural modeling different models appeared and different works appeared and the commercial and large commercial current conditions, and their climatic issues, logical. Here, there is no comprehensive framework that defines the technical foundations and standard specifications that apply to modular ceilings, and whether they can be applied to parametric ceilings., Therefore, the primary objective of the research paper is to determine the technical foundations and standards measured for the design of standard ceilings, such as acoustic performance and fire performance. On one crucial question: What are the principles by which architects create suspended ceilings?

3. The design of commonly suspended ceilings?

The design of suspended ceilings evolved through history accordingly with the evolution of design tools and techniques. Recently, digital drawing and design tools offered designers a remarkable ability to imagine how ceiling systems change over space and time.

The designers depend on the visualization abilities of the recent programs and the digital fabrication tools and machines that have excelled in forming, bending, cutting, and sculpting complex forms and designs. CAD, CAM, and ECAD facilitated the design and fabrication processes of suspended ceilings such as AutoCAD, Sketch-up, and & BIM programs like Revit.

Despite the diversity of selling materials and installation techniques, there are three common design principles: -

1- The Ceiling is divided into modular squares expressing the ceiling tiles,

2- The Ceiling in the entire area with multiple levels with spotlighting and concealed lights, such as gypsum boards, and so-called dry walls.

3- A Combined system of both techniques.

Additionally, Designers can also add artistic touches with other materials such as wood, metal tiles, or decorative shapes.

Due to the diversity of architectural spaces and their requirements, such as sound absorption, fire resistance, and light reflection. The designers should understand the space requirements and find the most appropriate solution with a wide range of products with diverse shapes, colors, and materials.

4. The design process of parametric ceilings:

In the case of parametric design, designers mostly employ visual scripting tools (e.g., grasshopper 3D) for modeling complex shapes, creating frequently used custom objects, and automating workflows. Once all the parameters are defined, the relationships between components or activities are set up. As a result, when a modification to the design is required, less time is needed to do these modifications as components are associated and the model can be updated accordingly. [1]

The first stage, in that case, is that the designer enters the space's geometrical parameters into a design tool. Then, the designer creates the relationships between the ceiling parameters via computer processing. [35] Consequently, the modeled elements can react accordingly dependent on the component parameters and rules. [1]

This intricate process creates a list of results and solutions based on geometric and mathematical correlations. [35]

The designer then utilizes these variables/parameters to investigate ceiling design options by switching between modeling and visual scripting interfaces. Such a process lets the designers experiment, visualize, simulate, and evaluate the solutions seamlessly, then they can fabricate the design building in real life.

However, what is the necessity of this design? Designers can adjust each panel's size and shape according to the changing shape of the ceiling's details. Each change influences all other adjacent panels. [36]

5. The common types of suspended ceilings:

There are diverse classifications for the typologies of suspended ceilings, as they may be categorized according to their materials (e.g. wood, metal, glass fibers), their suspension system (e.g. visible or concealed), or the performance the ceiling can provide (e.g. acoustic or thermal), as shown in Table 1.

In this research, the classification of the suspended ceilings according to their materials is employed to investigate their characteristics and their design considerations. The materials mentioned here are for the visible parts of the ceiling, whether it is panels, tiles, or strips:

According on the composition	
Mineral Fiber	
Wood	
Metal	
Soft fiber (glass fibers, Rockwool)	
Gypsum	
Fabric	
Mesh	

According on the Performance	
Sound absorption	
Sound attenuation	
Fire reaction	
Light reflectance	
Humidity resistance	
Indoor air quality	

According on the composition					
Exposed Grid		Concealed Grid (mineral fiber)		Concealed Grid (Metal Tile)	
	Hanging By Wire (canopy)				

Table 1: Ceiling types, performance, edge detail (Author)

5.1 Mineral Fiber:

Ceiling tiles are made from a variety of processed, recycled, and natural materials, depending on the tile type. Materials used include recycled newsprint, clay, perlite, starch, and fiberglass. [37]

The History of mineral fiber tiles goes back to the beginning of the nineteenth century, but it developed and evolved through many stages until it reached the recent version. The production works completely without the intervention of any labor except for people who work on programming and follow-up product quality and production lines.

Figure 1: mineral fiber production line (source 38)

Mineral fiber tiles are considered a modular product that cannot be manufactured in complex shapes except for orders with massive quantities, as was indicated in the production line and the higher cost of set-up charges. This type's most popular sizes are 600x600 mm and 600x1200mm, and they are installed on a hanging grid, visible or semi-hidden, or completely hidden.

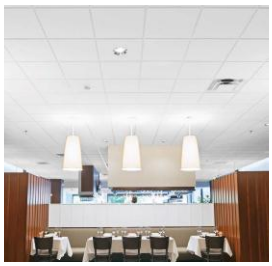

Figure 2: Photo of a mineral fiber suspended ceiling (Source: Armstrong Catalogue page 226)

5.2 Rock wool:

It consists of volcanic basalt stones, slag (which is waste from smelting the raw metal), in addition to recycled materials, whether from the same production line or other industries.

This type of ceiling is produced as modular units starting from 600x600mm up to 1200x2400mm due to its lightweight, and it can be installed either on a virtual suspension iron, or it can be installed completely hidden, as is the case in Seamless gypsum ceilings. This type is characterized by high sound absorption as its pores are large and its density is low [39].

Figure 3: The essential components of rock wool tiles (Source: Technical training for the researcher 2018)

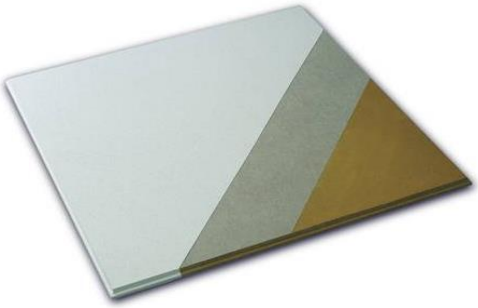

Figure 4: Rockwool tile source (Arsenault, 2017)

5.3 Glass Wool:

It is very similar to the type of rock wool in terms of lightness and sound absorption but differs in the materials that make up the tile, as it consists of glass wool instead of rock wool. [39]

Figure 5: fiberglass tiles, source [29]

5.4 Gypsum:

Gypsum is one of the basic raw materials for most interior finishing products (walls and ceilings). Gypsum has been used for a long time in construction and interior design due to its natural fire-resistant properties.

It consists of gypsum, which is a widely available material, fiberglass, and a large amount of water[40]. It has a variety of two types, one of which is modular (usually 600 * 600 mm) and covered with a layer of vinyl, which gives a decorative shape, and the other benefit is that gypsum in this size needs a surface that maintains its texture, and it is made of gypsum; Installing these tiles on the same suspension system as the mineral fiber tiles (Modular systems) [41].

As for the other type of gypsum ceiling, which is the panels, it is the most common and used because it can achieve different and varied decorative forms in sizes and heights. The board size is 1200 X 2400 mm, and it comes with thicknesses ranging from 12.5 mm to 18 mm.

Figure 6: The shape of one of the gypsum tiles covered with a layer of vinyl.

5.5 Wood Ceilings:

Wooden ceilings are among the decorative ceilings that give the luxury and richness of the space, as they are expensive. They consist of medium-density fiberboard or compressed wood chips and resin covered with a natural wood veneer. A thin layer of wood is sliced from a solid piece and glued to a chipboard, fiberboard, or similar material. The material looks like solid wood, with a natural wood grain finish, but most of the thickness of the tile or plank pieces is a composite material. [42]

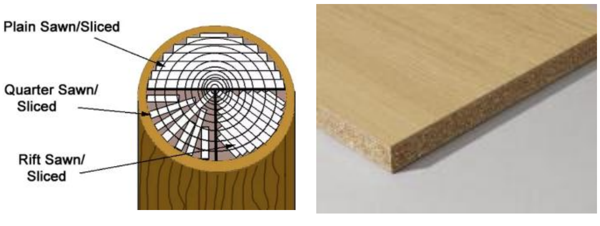

Figure 7: Shows the shape of the panels covered with Types of saw cuts and grilled ceiling panels,[30, 42]

Its shapes are varied, as they can be manufactured in different and multiple shapes and sizes due to the ease of handling and the availability of tools used in manufacturing and cutting them. (researcher)

Figure 8: Distinguished design and not commissioned for one of the theatres at the University of the Pacific in America [31].

5.6 Plastic ceilings:

Such ceilings employed materials such as PVC or PU, to add an aesthetical touch or effects (e.g. wood or Marble). (researcher)

Figure 9: Plastic tiled ceiling (source: Armstrong catalogue)

5.7 Stretch ceilings:

Consists of two main elements, the first is the metal frame consisting of extruded aluminum profiles, and the second element is the fabric or PVC plastic with a thickness starting from 0.2 mm. This fabric is stretched inside the aluminum sectors, and it can be absorbent for sound (micron perforation), as well as lighting can be placed behind it, and it can be printed on it. [43]

The Material is maintenance-free, hygienic, and nontoxic and is fire rated to new Euro-class Standard B s1 d0 and B s2 d0 in accordance with EN 13501.1, equivalent in the UK to Class' O'. The fabric is also UL Classified as equivalent to ASTM in the United States. [43]

Figure 10: Some fabric ceiling designs [33]

5.8 Metal Ceiling:

Metal ceilings are considered one of the most popular types of suspended ceilings; whether they are for new buildings or buildings that are being renovated, metal ceilings are long-lived and visually attractive in addition to their mechanical strength and recyclability.

It can be modular or with custom sizes, starting from a width of 228.6 mm and a length that can reach 2438.4 mm. As for the design of joints and edges, they are variable by changing the suspension system. [46]

Metal ceilings can be produced from Aluminum, iron, or stainless steel [44], and they are produced with different thicknesses, starting from 0.40 mm up to 1.00 mm. [45]

Figure 11: One of the corridors shows a retractable roof - Source Catalogue Armstrong BH600.

5.9 Mesh Ceilings:

They are tiles that contain slots employing pressure machines to form plates of different and varied sizes that give decorative shapes, and at the same time, they can be used as air suction slots in central cooling and air conditioning systems. (researcher)

Mesh panels provide an industrial look for interior spaces in a variety of standard sizes, patterns, and finishes. [47]

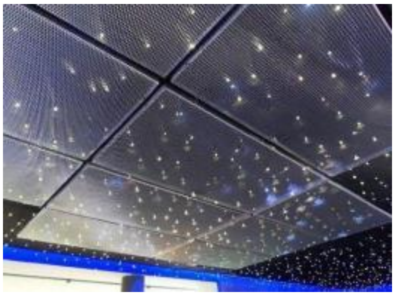

Figure 12: Picture of mesh ceilings [32]

Figure 13: Some forms of retinas [33]

6. The technical characteristics of suspended ceilings:

Each country has its standard specifications and code of practice for implementing suspended ceilings in buildings such as the Egyptian building code. This research focuses on the standard specifications set by The American Society for Testing Materials (ASTM), which is considered a main reference for other standards defined in many countries, especially the middle east.

The ASTM established a standard classification system for acoustic ceiling products based on their kind, pattern, and particular ratings for acoustic performance, light reflectance, and fire safety. [8]

*6.1 Format of Classification of the acoustical ceiling tile according to **ASTM E 1264**:*

-Ceiling Attenuation Class (CAC)
-Articulation Class (AC
- Noise Reduction Coefficient (NRC)
-The American Culture for Testing Materials (A.S.T.M)

The ceiling classification shall follow the format specified below:

Pattern; Type [Form]; NRC or AC (specify); CAC; LR; Fire Class For instance, a softly textured, water-felted mineral base ceiling with a painted finish that has an NRC of 0.70, an AC of 190, a CAC of 39, an LR of 0.82, and a flame spread rating of 50 would be classified as one of the following:

Alternatively, Type III, Form 2; Pattern E; NRC 0.70; CAC 39; LR 0.82; Fire Class B; or Type III, Form 2; Pattern E; AC 190; CAC 39; LR 0.70; Fire Class B. [8]

6.2 Type & Pattern:

- The Types:

The ASTM classified the acoustic suspended ceilings according to the raw material and the manufacturing method, whether cellulose, mineral fiber, fiberglass, Aluminum, or steel strip with backing, or type XX—Other types. [8]

- The Patterns**:**

Specifications indicated acoustical ceilings may have one or more of the several designs available, including perforated, light, heavily textured, smooth, or rough surfaces, and here the architect can specify the pattern accurately and clearly.

6.3 Acoustical Ratings:

A room's acoustics are comprised of sound that passes straight to our ears and sound that is reflected off the walls and other barriers. A diffuse acoustic field occurs when the sound intensity is uniform across the room because of large-scale reflections.

Sound reflects off a hard polished surface in the same way as light reflects. [15]

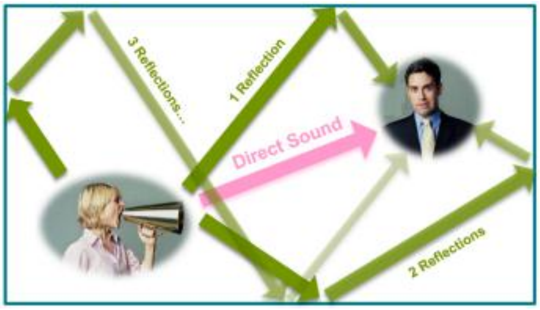

Figure 14: Reflections of sound through different surfaces (Source training in Armstrong office by Rob Gardiner 2010)

*6.3.1 Noise Reduction Coefficient (NRC)***:**

Sound absorption coefficients are used to calculate a single-digit rating by ASTM C 423, Method 11.7; It calculates an estimate of the sound-absorbent property of acoustical material. [3]

Rooms are constructed and furnished with a combination of materials, each with a different absorption coefficient. For most common materials, the ability to absorb sound varies with the frequency of the sound. To give a valuable and broad concept of a material's ability to absorb sound at various the noise reduction coefficient is calculated by averaging the absorption coefficients at 250, 500, 1000, and 2000 Hz NRC. [15]

A room with a long reverberation time of several seconds will cause syllables to be prolonged to overlap and degrade speech intelligibility. Long reverberation times can occur in large rooms with rigid walls and ceiling surfaces. [18]

NRC is used to describe the acoustic absorption performance of large surfaces of the material. It is not used to define the absorption provided by individual sound absorbers suspended over a room or placed into a room, such as ceiling baffles and islands. [23] Sabin is the sound absorption unit used for acoustic baffles, islands, and other three-dimensional sound absorbers placed or suspended inside rooms. [23]

6.3.2 Articulation Class (AC):

AC reflects the ceiling's ability to attenuate speech that might bounce off the ceiling above partial-height cubicle walls in open office environments. AC is the total of weighted sound attenuations in a series of 15 test bands (200 Hz to 5000 Hz). [4]

Meaning that the ceiling provides privacy by reducing the reflection above cubicle partitions, which makes it easier to understand the ceiling's reflections. The ASTM E1110 and E1111 standards are used to measure AC. [4]

AC is not popular nearly as much as NRC because of AC's limited application and its unit-less numeric values that are difficult to recognize. [23]

When the test is operated in a mock-up of a planned building or a finished building, strict adherence to the test method may not be possible in that the requirements of ceiling height and plenum depth, etc., cannot be satisfied due to the building design. Under these circumstances, the measurements apply only to that situation and other identical situations. [2]

In addition to the nominal ceiling, the level shall be defined as that of the exposed surface of a continuous flat ceiling or the lowest exposed surface of a nonflat ceiling. If the ceiling height and plenum conditions cannot be met in a field test situation, this test method may be used to assess the test setup and may not be used to obtain general Interzone attenuation data for the ceiling system. [5]

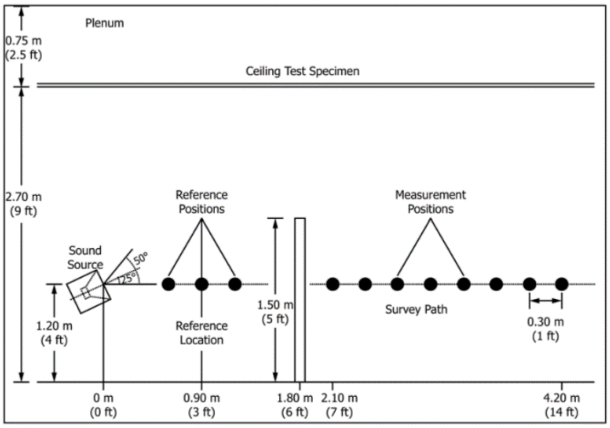

Figure 15: ceiling test facility according to ASTM E 1111

6.3.3 Ceiling Attenuation Class (CAC):

Measures the ceiling system's ability to prevent airborne sound transmission between adjoining closed rooms such as offices via a shared plenum are called CAC. [14]

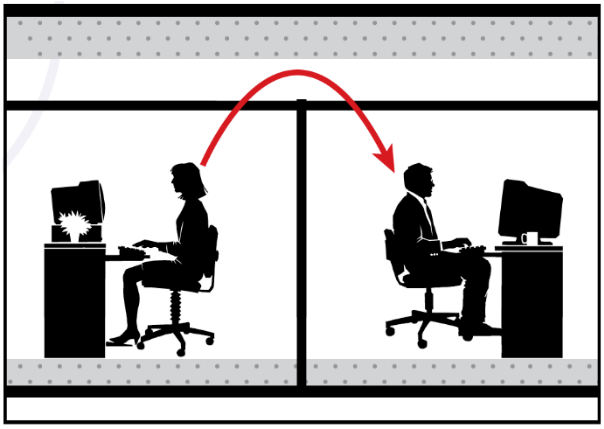

Figure 16: Sound transmission through a common plenum.

CAC does not apply to open offices. It should not be included in specifications for ceiling panels in large open spaces without walls. [21]

A CAC rating can be obtained by using Test Method E 1414 and Classification E 413 for an acoustical ceiling. From 5 dB to 55 dB, CAC values might range. [8]

The ASTM E 1414, titled standard test method for airborne sound attenuation between rooms sharing a common ceiling plenum, has set strict standards for CAC's test as shown in the below points: [10]

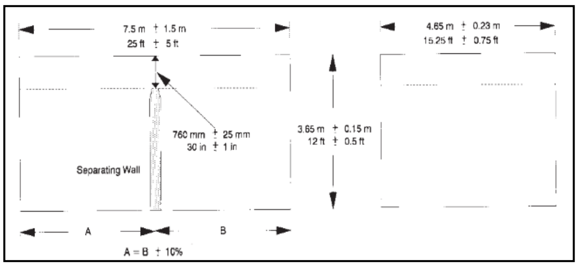

Figure 17: General Dimensions of the Test Room.

6.4 Light Reflectance (LR):

Only a portion of the light reflecting off an object enables the eye to see it. A featureless black silhouette would seem as if an object reflected no light. The absence of any visible light hues is what is meant by the term "black." While white is defined as having the same amount of each color in the light spectrum, this is not necessarily the case. As a result, materials that aren't black or white must fall someplace in between. [6]

benefits of High- Light Reflectance Ceilings:

Two important lighting sources in a workplace are natural daylight and electrical lights. the room's overall illumination and uniformity are boosted by a well-designed ceiling with intense light reflectance, directly affecting working comfort, well-being, and productivity. [28]

Color characteristics are important to keep in mind when choosing a color scheme or setting a mood since they help save energy in places like offices, schools, and homes by not using as much lighting or air conditioning when a color with a higher light reflectance value is used.) [27]

- Energy savings of up to 11% for the entire building can be achieved by using indirect lighting.
- High-light reflectance ceilings contribute to BREEAM, LEED, DGNB, HQE, and Ska credits by improving visual comfort. They also save 7% of the energy used in the cooling system. [28]

6.4.1 Light Reflectance Value (LRV):

Paint surface LRV is a measurement of how much visible and useful light can be bounced off of it (or absorbed into). LRV is a metric used to determine how much light a particular hue of paint reflects. [27]

It is possible to quantify LRV from 0% (complete black, which absorbs all light and heat) up to 100% (pure white, reflecting all light). These measures are used by architects and designers to make educated guesses about how light or dark a color will seem in a space. [27]

Authentic physical materials vary from about 5% for the darkest of matte blacks up to 85% for the brightest white color, though some fluorescent yellow materials can measure up to 90-92%.[22]

The Americans with Disability Act Accessibility Guidelines (ADAAG) advise a 70% light reflectance value or greater for impaired vision, but it is not a strict condition. Many color combinations in the 60-70% range work well. [27]

The following table presents the light-reflecting factor for some materials:

Table 2: LRV for some materials. [26]

Material	Reflection Factor (%)
Body where no light is reflected (Black body)	0
Paint, dark blue, dark green, dark red	15 - 20
Plaster, dark	15 - 25
Paint, brown	20 - 30
Oak, light polished	25 - 35
Paint, medium grey	25 - 35
Plywood, rough	25 - 40
Plaster, light	40 - 45
Paint, light green	45 - 55
Stainless steel	50
Nickel, highly polished	50 - 60
Aluminum coatings, matte	55 - 56
Aluminium, matte	55 - 75
Chrome, polished	60 - 70
Paint, light yellow	60 - 70
Aluminum, polished	65 - 75
Vitreous Enamel, white	65 - 75
Copper, highly polished	70 - 75
Paper, white	70 - 80
Paint, white	75 - 85
Aluminium, anodized, matte	80 - 85
Lacquer, pure white	80 - 85
Pure aluminum with a mirror-like finish.	80 - 87
Stained-glass window with silvered mirror on the other side	80 - 88
Silver, highly polished	90 - 92
Body where all light is reflected	100

6.4.2 Light Reflection Measurement:

The ASTM E1331 & E 1164 have defined the light reflection measurement method using a spectrophotometer or spectrocolorimeter outfitted with a hemispherical optical measuring system, such as an integrating sphere [9]

When mentioning building materials, the term reflectance usually is shown to mean hemispherical Reflectance. Relative fractions of the radiation return to the hemisphere in which the zenith is usually to the surface plane and on the same side of the surface as the radiation source, as indicated in the following figure. [22]

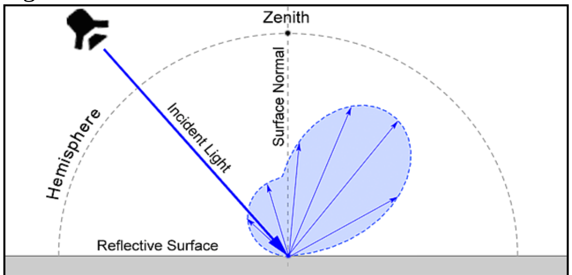

Figure 18: hemispheric reflection on the same side of the surface as the incident light. [11]

6.5 Fire Class/Surface Burning Characteristics :

More than 80% of fire-related deaths are caused by smoke inhalation, and the bulk of these deaths are caused by residential fires. Pathophysiology of smoke inhalation involves multiple factors, such as hypoxia, thermal damage, and numerous chemical poisons, all of which have an additive or synergistic harmful effect (e.g., hydrogen cyanide, carbon monoxide, irritant gases).

In patients who have inhaled smoke, asphyxia is the leading cause of death (i.e., tissue hypoxia and consequent acidosis). The carboxyhemoglobin fraction is high in nearly all patients with signs and symptoms of asphyxia. [20]

The ASTM E 84 test method can be used to classify acoustical ceiling products based on their flame spread and smoke-developed indexes [8]. The goal of this test method is to determine the relative burning performance of the material by observing the flame spread along with the specimen in the ceiling place with the specimen exposed face down to the ignition source. The two metrics, however, aren't necessarily connected. [13]

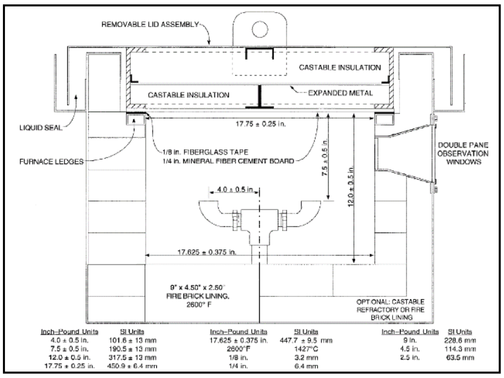

Figure 19: The Critical Dimensions of a Test Furnace (Not a Construction Drawing)

Figure 20: with the surface to be examined facing down toward the ignition source, the specimen is in the ceiling position [17].

Class A, B, and C are the three reporting categories, with a flame spread range of 25, 75, and 200.

There are three classes: A, B, and C, which are all identical to building code classes I, II, and III. [8]

For various materials and exposures, test Method E 84 results have shown similar performance to that reported during unintentional structure fires. However, it is important to note that the purpose of this method is solely to produce classifications that are comparative in nature. [13]

This method may not completely analyze the surface burning behavior of composite assemblies or panels with metal or mineral facings and combustible internal cores, which remain virtually impermeable to flame during the test period. [13]

During the test, certain materials, such as composites, may come apart. In either case, the FSI (Flame Spread Index) may be increased or sagged or dropped into the fire chamber to slow the spread of the flame [13].

In certain materials, such as thermoplastic and thermosetting polymers, it may be difficult to determine their properties because they are so complex. All items that are not mechanically attached will fall to the tunnel floor, resulting in low FSI ratings for thermoplastic and thermosetting materials [13].

The materials described above, those that drip, melt, delaminate, draw away from the fire, or require artificial assistance, have unique characteristics and issues and require careful interpretation of the test results. Some of these materials assigned a low FSI based on this method may exhibit an increasing propensity for generating flame-over conditions during room fire tests as the material's exposure area grows larger and the intensity of the fire grows stronger. The outcome, therefore, may not be indicative of their performance if evaluated under large-scale test methods. Alternative means of testing may be necessary to evaluate some of these materials fully [13].

According to the information mentioned earlier, the test ASTM E 84 can apply to all types of suspended material (modular and parametric) even if the size of the panel is less than 508 mm, as we are testing the surface burning characteristics (fire reaction), and not the fire resistance of the assembled or installed system according to the ASTM E 119 (fire reaction).

6.6 Fire Testing of Building Materials

Fire Tests of Building Construction and Materials have not been established as an ASTM rating, which should be one of the characteristics to be classified; however, we are presenting it here because it has a close relationship with people's lives and safety

The ASTM defines fire resistance as a material or assembly's ability to withstand or defend against fire [12].

The ASTM E 119 standard applies to assemblies for the test methods described in this fire-test-response standard.

This technique applies to floor and roof assemblies that have or do not have connected, furred, or suspended ceilings, and it requires the application of fire exposure to the underside of the specimen under test to be valid [7].

7. Summary of the ASTM standards:

Table 3: Summary of suspended ceilings compliance with international standards.

Technical characteristics	ASTM Standard	The definition
Type	E 1264	The ASTM divides the acoustic suspended ceilings according to the raw material made of and the manufacturing method.
Pattern	E 1264	Acoustical ceilings may be a combination of one or more patterns, like perforated or textured.
Noise Reduction Coefficient (NRC)	C 423, E 795, C 634	According to ASTM C 423, this is a single-number rating based on observed sound absorption coefficients.
Articulation Class (AC)	E 1110, E 1111, C 634	In open office areas with partial-height cubicle walls, this value indicates how well the ceiling can dampen speech reflected off the surface.
Ceiling Attenuation Class (CAC)	E 1414, C 634	Suspended ceiling systems are rated on their ability to reduce airborne noise transmission from nearby confined areas, such as offices.
Light Reflectance (LR)	E 1331, E 1477	A measure of the quantity of visible and usable light that reflects (or is absorbed into) a painted surface as a percentage of the total amount of visible and usable light.
Fire Reaction	E 84	To determine the relative burning behavior of a material, observe the flame spread while the specimen is hanging from the ceiling, with its face down toward the ignition source
Fire Resistance	E 119	A substance or assembly can endure fire or protect against it.

8. Design process framework

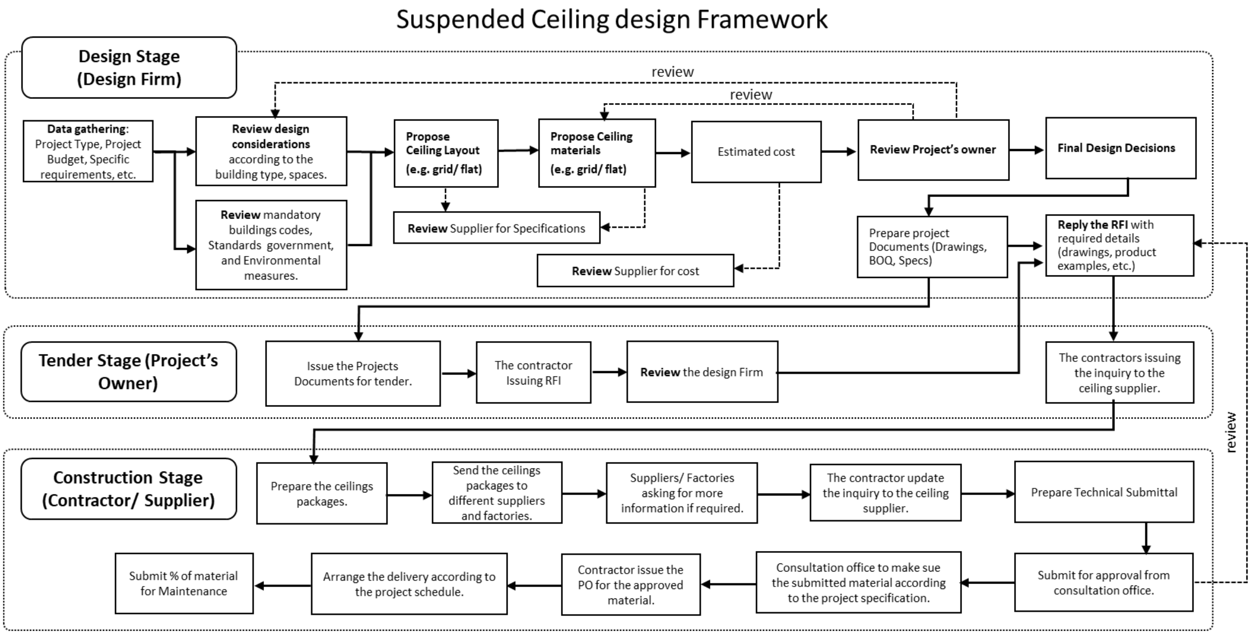

Figure 21: Design process framework Prepared by authors

Design Stage (Design Firm)

A suspended ceiling (sometimes referred to as a false ceiling or dropped ceiling) is a modern architectural component that is now mandatory for technical and commercial properties and also becoming increasingly popular for residential use as well.

To design an effectively suspended ceiling it is advisable, first of all, to know the different types that are available on the market.

A false ceiling can be classified according to the type of structure and the type of panel.

Depending on the type of structure, we can distinguish:

False ceiling in adherence | consisting of a metal framework, fixed directly to the slab employing special connection hooks, to which the selected slabs are placed for the intervention.

suspended false ceiling | consisting of suspension and support elements (steel hangers) that are suspended and connected to the floor slab holding the metal frame.

self-supporting false ceilings | The metal support structure Does not rest on the ceiling, as in the two previous cases, but on the perimeter walls through steel profiles.

Tender Stage (Project's Owner)

Contain three parts Issue the Projects -Documents for tender-The contractor Issuing RFI

The structure can be exposed, flush, recessed, or concealed with removable inspection panels according to a wide range of different grid profiles, tile edge details, and interlocking metal sections.

1- Suspended Ceiling Panels Are Generally Made Of Plasterboard, Rock Wool, Or Other Insulating Materials To Choose From According To The Design Requirements But You Can Also Find Some Innovative Solutions, Such As Panels That Are:
2- Optimized For Thermal And Acoustic Regulation
3- Earthquake-Proof
4- Moisture Resistant
5- Modular
6- With High Sound-Absorbing Capacity
7- With Wooden Slats
8- With Integrated Lighting
9- With Customizable Backlighting Decorations
10- In Membranes Made With A Shape-Memory

Polymer (Tensorial Or Stretched Ceilings).
Review the design Firm

Useful tips for designing a suspended ceiling

1- When planning a suspended ceiling it is essential to pay attention to the premises' heights.
2- According to the Egyptian code. building standards, it is required" a minimum ceiling height of 3 meters address the unique heat effect of and the distinct density and flatted nature of most of its residential l area is strongly encouraged so that new housing is of adequate quality, Construction Stage (Contractor/ Supplier).

As we have mentioned in the introduction, designing a suspended ceiling combines technical and functional advantages with aesthetical ones. A suspended ceiling:

1- Contributes To The Acoustic And Thermal Insulation Of The Environment In Which It Is Installed
2- Allows You To Easily Conceal Electrical Wires, Pipes, Heating And Air Conditioning Systems
3- Envisages Different Types Of Lighting, Including Recessed Light Fittings
4- Helps To Re-Proportion Environments
5- Significantly Changes The Appearance And Use Of An Existing Environment With Small Efforts
6- Is A Safe And Cheap Material
7- Guarantees Great Freedom Of Design.

9. Conclusion:

The parametric plan had another way to deal with innovator design. It permits planners to make changes to roofs naturally, decreasing the time, and exertion expected to execute, and physically play out these adjustments. Creators could remove human blunders from the situation, and limit manual redundancies. The demonstrating, and the prearranging climate permit draftsmen, and fashioners to explore different avenues regarding the design's computerized texture to reproduce the construction, in actuality. Modelers could change each board's size, and shape to change the state of the roof's different subtleties.

Additionally, the after-effects of the introduced study had shown the deliberate specialized establishments, and rules for planning parametric roofs. It likewise expected to lay out a point-by-point comprehension of the suspended roof exhibitions. Also, it had shown the sorts of the parametric roof as indicated by the essential methodology of the parametric plan. Coming to the consequences of the secluded roofs tests could be summed up to every one of the amounts created from the very item that conveys similar fixings whenever, as needs be, an information sheet could be given for designers to use in their tasks as a source of perspective with stable logical proof.

The further result is that the vast majority of the roof execution of the design spaces, addressed in acoustics, and vision, notwithstanding imperviousness to fire, can't be applied overall to parametric roofs because of the distinction of numerous extraordinary boundaries, whether the test climate, the shape, size of the test example or the heading of its establishment.

Finally, the research presented the **ASTM** standards for suspended ceilings to have a comprehensive understating of the design limitations and constraints related to the material selection process. The study of the standards revealed more challenges in the material selection process, and the designer should define the design priorities based on the expected activities in the space that should be designed. For example, some materials have better acoustic performance however they have less fire resistance, and vice versa. Issues like that make the design process more challenging in terms of material selection.

Consequently, it is important to make the designers understand the designing techniques (e.g. using CAD) and the properties of materials used to manufacture suspended ceilings to choose the most appropriate material and designs for the space. Also, it is important to improve the communication between the designers, contractors, and manufacturers to obtain feasible and appropriate design solutions with fewer issues and risks.

10. Recommendations

-Since this paper only analyzed the effects of the parametric design on the creativity of the designers; the researchers, therefore, recommended concentrating on kinetic interior design structure, walls, and materials used in inner spaces and their effect on the psychology and behaviors of the users.

- The need to apply for modern design programs as an integral part of the educational system in specialized colleges such as engineering and applied arts to keep students pace with modern technology and the requirements of the labor market.

References

[1] Allplan. (2019, October 15). Visual Scripting – The Alternative to Programming. (Allplan a nemetscheckcompany) Retrieved July 22, 2021, from allplan.com: https://blog.allplan.com/en/visual-scripting-the-alternative-to-programming

[2] ASTM C423-17. (2017). Retrieved from Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method, ASTM International: https://www.astm.org/Standards/C423.htm

[3] ASTM C634-13. (2021). Retrieved from Standard Terminology Relating to Building and Environmental Acoustics: https://www.astm.org/Standards/C634.htm

[4] ASTM E1110-06. (2019). Retrieved from Standard Classification for Determination of Articulation Class: https://www.astm.org/Standards/E1110.htm

[5] ASTM E1111 / E1111M-14. (2014). Retrieved from Standard Test Method for Measuring the Interzone Attenuation of Open Office Components: https://www.astm.org/Standards/E1111.htm

[6] ASTM E1164-12(2017)e1. (2017). Retrieved from Standard Practice for Obtaining Spectrometric Data for Object-Color Evaluation: https://www.astm.org/Standards/E1164.htm

[7] ASTM E119-19. (2019). Retrieved from Standard Test Methods for Fire Tests of Building Construction and Materials: https://www.astm.org/DATABASE.CART/HISTORICAL/E119-19.htm

[8] ASTM E1264-19. (2019). Retrieved from Standard Classification for Acoustical Ceiling Products, ASTM International, West Conshohocken, PA: https://www.astm.org/Standards/E1264.htm

[9] ASTM E1331-15. (2019). Retrieved from Standard Test Method for Reflectance Factor and Color by Spectrophotometry Using Hemispherical Geometry: https://www.astm.org/Standards/E1331.htm

[10] ASTM E1414 / E1414M-21. (2021). Retrieved from E1414M-21, Standard Test Method for Airborne Sound Attenuation Between Rooms Sharing a Common Ceiling Plenum: https://www.astm.org/Standards/E1414.htm

[11] ASTM E1477-98A(2017)e1. (2017). Retrieved from Standard Test Method for Luminous Reflectance Factor of Acoustical Materials by Use of Integrating-Sphere Reflectometers, ASTM International: https://www.astm.org/Standards/E1477.htm

[12] ASTM E176-18ae1. (2018). Retrieved from Standard Terminology of Fire Standards: https://www.astm.org/Standards/E176.htm

[13] ASTM E84-21. (2021). Retrieved from Standard Test Method for Surface Burning Characteristics of Building Materials, ASTM International: https://www.astm.org/Standards/E84.htm

[14] AWI. (2021). HIGH CAC CEILINGS. Retrieved from www.armstrongceilings.com: https://www.armstrongceilings.com/pdbupimages-clg/209461.pdf/download/related-brochure-cac.pdf

[15] BINGGELI, C. (2003). Building systems for interior designers. New Jersey: John Wiley & Sons, Inc.

[16] Chan, B. (2011, August 18). The Conga Room / Belzberg Architects. (ArchDaily) Retrieved August 13, 2021, from www.archdaily.com: https://www.archdaily.com/160584/the-conga-room-belzberg-architects

[17] Crimi, T. (2018, February 13). ROCKWOOL and the ASTM E84 Test Method. Retrieved from Youtube: https://www.youtube.com/watch?v=qefCCVKVBKA

[18] David Canning, N. C. (2015). Acoustics of Schools: a design guide. Unknown: Published jointly by the Institute of Acoustics and the Association of Noise Consultants.

[19] K.Chai, Shutsu. June 2006. *The Design & Construction OF Interactive Architectural Environments: The Digital Mile, Zaragoza, Spain.* s.l. : Department Of Mechanical Engineering, MIT, June 2006.

[20] Linden, C. H. (2007). Chapter 86 - Smoke Inhalation. In S. Michael, B. Stephen, & B. Michael, Haddad and Winchester's Clinical Management of Poisoning and Drug Overdose (Fourth Edition) (p. 1283). Philadelphi: Saunders, an imprint of Elsevier Inc.

[21] Madaras, G. (2019). How to absorb open office sound. Commercial Architecture Magazine, 17(4), 19.

[22] Marsh, A. (2010, November 09). Light Reflectance. Retrieved from Performative Design: http://performativedesign.com/definitions/light/reflectance/

[23] Rockfon North America. (2021, May 10). Acoustic absorption, high NRC, improves human wellbeing – The evidence is clear. Retrieved from rockfon: https://www.rockfon.com/products/product-benefits/acoustics/acoustic-absorption/#sabins

[24] Skrinnikoff, A. (n.d.). Wave Blades. (Supawood Architectural Lining Systems) Retrieved October 15, 2018, from www.supawood.com.au: https://www.supawood.com.au/products/wave-blades/

[25] Swaidan, A. (2016). Parametric concept and its applications in interior design and furniture. Cairo: Damietta University.

[26] The Engineering ToolBox. (2012). Materials - Light Reflecting Factors. Retrieved from Engineering Toolbox: https://www.engineeringtoolbox.com/light-material-reflecting-factor-d_1842.html

[27] Vogel, D. (2016, September 19). What is LRV? (Diamond Vogel) Retrieved from Diamond Vogel: https://www.diamondvogel.com/architectural/blog/what-is-lrv

[28] Zentia. (n.d.). Light Reflectance. (Enigma Interactive) Retrieved from Zentia: https://www.zentia.com/en-gb/performance/light-reflectant-ceilings

[29] Woodbury, R. (2010). *Elements of Parametric Design.* Oxon: Routledge.

[30] Archistar. (n.d.). *How Will Parametric Design Impact Industry in 2020 and Beyond?* Retrieved 07 22, 2021, from https://archistar.ai/: https://archistar.ai/blog/how-

will-parametric-design-impact-industry-in-2020-and-beyond/

[31] Coorey, B. (n.d.). *How Will Parametric Design Impact Industry in 2020 and Beyond?* Retrieved from Archistar: https://archistar.ai/blog/how-will-parametric-design-impact-industry-in-2020-and-beyond/

[32] ceilingtilesuk (n/a). Retrieved from What Are Suspended Ceiling Tiles Made From?: https://www.ceilingtilesuk.co.uk/what-are-suspended-ceiling-tiles-made-from/

[33] AMF,K (2016). http://www.amf-cz.cz Retrieved from http://www.amf-cz.cz: http://www.amf-cz.cz/cze/historiecz.html

[34] Mono, R. (2022, April). Rockfon® Mono® Acoustic. Retrieved from https://www.rockfon.co.uk/: https://www.rockfon.co.uk/products/rockfon-mono-acoustic/?selectedCat=datasheets%20tiles%20and%20panels#Performance

[35] Superstore, I. (n/a). Glass wool or mineral wool – which is best for insulation? Retrieved from https://www.insulationsuperstore.co.uk: https://www.insulationsuperstore.co.uk/help-and-advice/product-guides/insulation/glass-wool-or-mineral-wool-which-is-best-for-insulation/

[36] Owen, J. D. (1993, May 16). Process for the manufacture of ceiling tile. Retrieved from https://patents.google.com/: https://patents.google.com/patent/US5194206A/en

[37] Gyproc. (2019, June). Gyproc Ceilings Installation Guide. Retrieved from www.gyproc.ie: https://www.gyproc.ie/sites/default/files/Gyproc%20Ceilings%20Installation%20Guide%202019%20Final.pdf

[38] King, T. (n.d.). What Type of Wood Is Used for Ceilings? Retrieved from www.ehow.com: https://www.ehow.com/about_5183129_type-wood-used-ceilings_.html

[39] StretchCeilingsMELimited. (2020). What is a Stretch Ceiling? Retrieved from https://www.stretchceilings.ae/en/explore/stretch-ceilings

[40] Gsearch. (2020, May 28). What are the different types of metal ceilings available? What are its benefits? Retrieved from tranquil.global: https://tranquil.global/what-are-the-different-types-of-metal-ceilings-available-what-are-its-benefits/

[41] Gopinath, V. (2020, May 25). Metal False ceiling Types -Clip in and Lay-in Tile. Retrieved from vincivilworld.com: https://vincivilworld.com/2020/05/25/metal-false-ceiling-types-of-metal-false-ceilings/

[42] AWILicensingCompany. (2000-2022). METALWORKS RH215 Plank and Faceted Custom Systems. Retrieved from www.armstrongceilings.com: https://www.armstrongceilings.com/commercial/en/commercial-ceilings-walls/custom-metal-ceilings/metalworks-rh215-flat-faceted-ceiling-system.html

[43] AWILicensingCompany. (2000-2022). Metal Mesh Ceilings. Retrieved from www.armstrongceilings.com: https://www.armstrongceilings.com/commercial/en/articles/metal-mesh-ceiling.html

[44] Arsenault, P. J. (2017, October). https://continuingeducation.bnpmedia.com/. Retrieved from The Value of Stone Wool Acoustical Ceilings: https://continuingeducation.bnpmedia.com/courses/rockfon/the-value-of-stone-wool-acoustical-ceilings/1/