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TECHNICAL DETERMINANTS OF THE DESIGN OF PARAMETRIC CEILINGS

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The research paper's primary goal is to identify the measured technical foundations and rules for designing parametric ceilings like acoustic and fire performance and respond to one critical question: What are the bases on which architects create parametric suspended ceilings? Moreover, establish a detailed understanding of the suspended ceiling performances and develop a detailed analytical set of considerations for designing the suspended parametric ceiling.

The outcome of this research shows four thematic parts. The first part is why the architects tend to design parametric ceilings, then the types of parametric ceilings; and the third part is the standards for designing modular ceilings provided by international factories—finally, Investigating the possibility of applying the technical properties of modular ceilings to parametric ceilings.

Keywords: *Parametric Ceilings, Parametric Design, Modular Suspended Ceiling, Ceiling performance*.

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I. INTRODUCTION

Parametricism pursues the general aim to organize and articulate the increasing diversity and complexity of social institutions and life processes within the most advanced centers of the post-Fordist network society. (Schumacher, 2016).

Parametricism is a term for a modern call epochal global architecture style (Chokhachian, 2014), and methodology based on parametric modeling and scripting techniques covers all the design disciplines and becomes an essential benchmark in architecture design (Schumacher, 2016). The term lately has developed a global movement that becomes mature in technology and contemporary architecture. Parametric design, in latest years, has become a motto as it is mainly used to design structures that respond to their environment, climatic problems, and contextual features. Simultaneously, it can operate as a powerful tool contributing to the realm of the design process in architecture design; however, it is only appreciated as physically applied parametric modeling techniques. (Chokhachian, 2014)

Designers continue to amaze us with new functions and forms. Sometimes new work embodies wisdom, a precious commodity in a finite world. The parametric systems bring creative and needed new capabilities to the human enterprise of design to adapt to context and contingency and explore the possibilities inherent in an idea. (Woodbury, 2010)

II. HOW ARE ARCHITECTS DESIGNING THE PARAMETRIC SUSPENDED CEILING?

The designers facilitate the ease of design by employing advanced programs such as Blender, SolidWorks, Maya, Rhino, ZBrush, and moving powerfully in this direction without the measured engineering regulations and technical performances, As is customary for modular suspended ceilings.

Architects use visual scripting, which is ideal for parametric modeling of complex shapes, creating frequently used custom objects, and automating workflows. Once all the parameters have been defined, the relationships between components or activities have been set up. As a result, when changes are required, less time is needed to implement them as components automatically update based on their defined relationships and behaviors. (Allplan, 2019)

Parametric tools are a technique of identifying design limitations to visualize design opportunities. Digital parametric tools grant interior designers and architects a more remarkable ability to imagine how ceiling systems change over space and time.

The designers depend on the formal dazzle arising from the ability of advanced programs and what can be accomplished by the innovative industries and machines that have excelled in informing, bending, cutting, and sculpting.

III. WHY THE ARCHITECTS TEND TO DESIGN PARAMETRIC CEILINGS

Parametric design can deal with a parametric ceiling with a complex structure whose structure was impossible to define previously and follow its structural system. The shapes' ceiling structures are based on employ those concepts in dazzling designs that are extraordinarily complex.

The parametric design allows modifications in any part of the ceiling design to occur automatically in the rest of the ceiling parts, even if dealing with the complex structure, reducing the significant time and effort required to implement and manually perform these modifications.

Parametric design has a dynamic visual impact; there is an excellent possibility of obtaining a dynamic ceiling system through the parametric concept.

The raw materials vary in the parametric design like wood, metal, and plastics; as the parametric design depends on the repetitive unit, due to the possibility of obtaining from it using laser cutting on an infinite number of units in various shapes, and textures and With infinite formations by simulating nature. (Swaidan, 2016). Which is enables mass customization rather than mass production and offers out-of-the-box solutions for architectural ceilings.

Safe the time (and money) on trial and error; since architects design, edit, evaluate and generate fabrication drawings seamlessly with the tool, they can take human error out of the equation and minimize manual repetitions. (Coorey, n.d.)

The "traditional" modernist architecture education is being replaced by a concept and approach of parametric design. (Thor Architects, n.d.) because recent design approaches rely on form-finding rather than form-making.

All of the data for the parametric project remains saved in the tool unless removed. This means it can be used as part of the previous project in designing a new one.

Furthermore, if the client demands a last-ditch change to specific details, there is an easy way to do so. (Hewett, 2020)

IV. HOW DO ARCHITECTS DESIGN PARAMETRIC CEILINGS:

First, enter the geometrical parameters of the space into a tool of design. Then, the system creates relationships between ceiling parameters via computer processing. (Archistar, n.d.) then the modeled elements behave intelligently based on parameters that are assigned to the components. (Allplan, 2019)

This complicated procedure generates a list of probable variables. Furthermore, It's all because of geometrical and mathematical relationships. (Archistar, n.d.)

Afterward, the designer uses these variables to explore ceiling design possibilities by moving between the modeling and the scripting environment to build the parametric design. It allows architects and designers to experiment with the structure's digital fabric. At the same time, they can be confident that they will be able to recreate the structure in real life.

However, what is the point of this design? Architects could adjust each panel's size and shape to change the shape of the ceiling's various details. That one change impacted all of the other panels connected to it. (Coorey, n.d.)

V. TYPES OF PARAMETRIC CEILINGS:

This part will seek to contextualize the application of different techniques indeed design and manufacturing the suspended ceiling. It will be evident that digital technologies have been transformative in the design process of architecture and present several new paradigms for generating and fabricating creative ideas. (DUNN, 2012)

V-1 Contouring Ceilings (Baffle):

The contour surface is the contoured surface with curves and slopes rather than being flat. The topographic surface contains highs and lows represented by lines called contour lines, and they are imaginary lines that connect all points on the surface with the same depression or height at a certain level. (Sinclair, 2018)

The exact previous definition applies to topographic or contour ceilings. It contains multiple and different heights and depressions that allow the formation of the topographic shape. It can be formed with baffles or by curved tiles that are grouped to form several levels.

Contouring changes this physical materiality by using an incremental subtractive technique, unlike carving, to provide three-dimensional features from what is ostensibly a 'flat' sheet material. (DUNN, 2012)

Typical materials used with this process are wood and foams, although metals may also be used. (DUNN, 2012)

Figure 1: Finished secretarial desk alloplastically linked to ceiling inflection One Main Office Renovation / dECOi Architect

Types of Contouring Ceilings:

Rain Drop:

It is a ceiling with a central point, often in the shape of a circle, containing a central area that changes the contour lines' movement towards the perimeter.

Irregular contouring ceiling:

This type needs a lot of study and

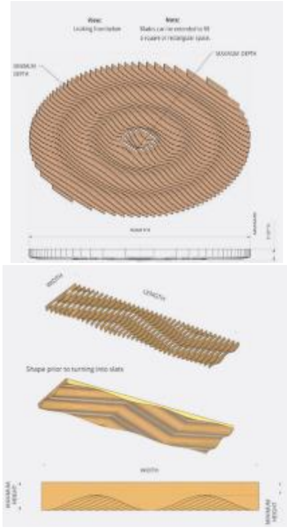

Figure 2: Raindrop-shaped topographic roof. (Skrinnikoff, n.d.)

Zigzag*:*

It is a frequent zigzag formation where the contour lines move in a regular, zigzag manner. Usually, this type is used in longitudinal spaces such as corridors and movement paths in open spaces such as offices; it is widely used in wood materials as the panels come with large areas of 1200 * 2400 mm.

Figure 3: Raindrop-shaped topographic roof (Skrinnikoff, n.d.)

Wave*:*

Much like a zigzag ceiling, but the contour lines move in a regular wave, forming an art form, and are also used in linear spaces.

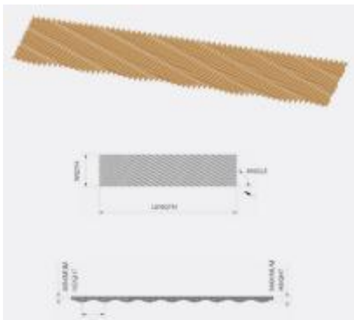

Figure 4: Raindrop-shaped topographic roof (Skrinnikoff, n.d.)

design for all suspended ceiling components, whether it is tiles or even the suspension system, and it may be produced in any form.

Figure 5: Irregular Topographical Ceiling of the Coty Professional Aesthetic Center United States (Dennis, 2020)

V-2Unfolded Ceiling (Island):

In comparison to contouring, folding is very economical in material terms. Already an engaging method of exploring design ideas at various scales, digital fabrication has afforded even further experimentation with this material operation. Perhaps the most immediate characteristic of folding is the continuity of space, surface, and form it provides, enabling a fluidity distinct from most other tooling methods (DUNN, 2012)

Geometric singularity is transforming a three-dimensional body shape into a two-dimensional flat to be expressed by drawing. modulated form, folding already has an extensive history in product design and other creative disciplines. However, digital-fabrication technology readily allows the designer to shift from a scale model to full-size spatial prototypes and installations (DUNN, 2012)

The data for these unfolded sheets are usually used with cutting machines – particularly laser cutters, although plasma and water-jet cutters may also be engaged for this process. The advantage of laser cutters is that they can score sheet material rather than cut through its thickness (DUNN, 2012)

The designer concludes that flat or individual ceilings are surfaces for geometric or artistic shapes that are individualized either manually if the shape is simple or by using programs if the shape is complex.

As a translation process, converting two-dimensional surface into three dimensional.

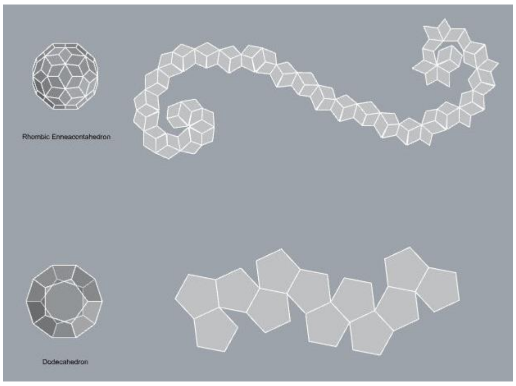

Figure 6: Individuals of the ball and the geometric shapes made of it. (Meier, 2017)

Figure 7: Ceiling resulted from the singling of the variable acoustic geometry study ball at the University of Michigan. (Furuto, 2012)

V-3 Sectioning (Open-Cell):

Sectioning is a method of profiling components concerning surface geometry.

Taking a series of sectional cuts through a digital model offers a quick and effective way of gathering the necessary data to inform a CAD/CAM process. Digital modeling software commands typically provide instant sections through a three-dimensional form. Using a series of such sections in parallel, it is immediately apparent how this will convert into a physical structure and surface. (DUNN, 2012)

This type of ceiling resembles the origami art of paper cutting, as it is very similar to assembling a certain number of sheets and pasting them together from the ends and then pulling them from the ends.

Unfolded ceilings are one of the types of suspended ceilings that can be developed into flat surfaces without deformation.

All roof panels are made with each other either by hinges, especially plastic or wood, or by welding if the panels are of metal, and then suspended by hanging wires directly on the structural soffit (Panchuk, 2006).

Figure 8: Sectioning Ceiling (Arktura, n.d.)

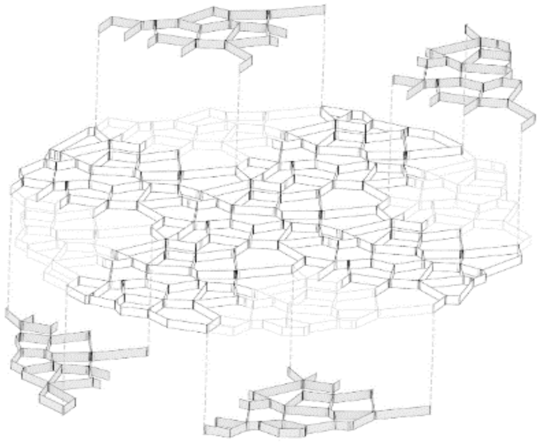

Figure 9: Method of grouping the unfolded units together (same as the previous source)

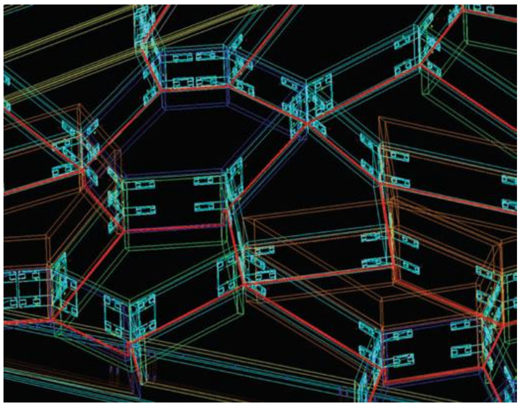

Figure 10: The connections between each structural 'cell' are determined using three-dimensional digital-modeling software to ensure the integrity and performance of both elements and the composite whole. (DUNN, 2012)

V-4 Tilling (Tessellated Ceiling):

Parametric tessellated surfaces are one of the most used algorithms in CAD applications. There are numerous studies of this type of surface that can be roughly classified into two parts; the first being uniform sampling and the second adaptive sampling, which is in the surface in The first range is divided into a uniform grid, where the surface is produced with shapes without increases or tolerance. The second type may result in some design errors that can be addressed by adding a more significant number of triangular surfaces

(Seok-Hyung Bae, 2002).

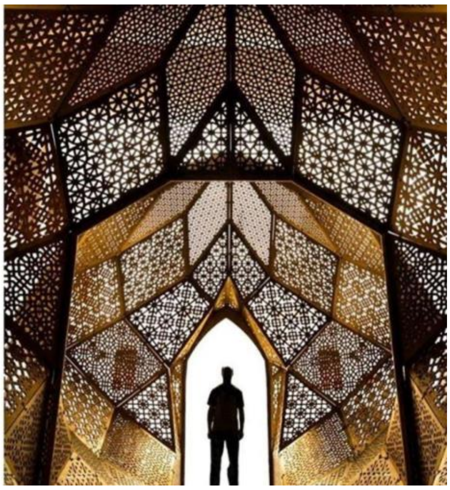

Figure 11: Bahrain national museum. (AbdulHadi, 2015)

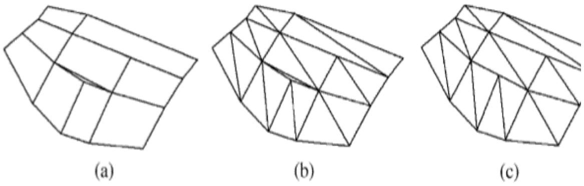

Figure 12: Clarifies the crack in the design that needed to add more surfaces (same previous source)

In the manufacture of ceilings, a group of panels or pieces are assembled to form a unified geometric shape that resembles this type of Islamic mosaic ceilings. This type of design depends on digital design programs as it cannot be deduced or designed manually due to its great need for imagination and creativity. This is considered The type of ceiling that is most amenable to manufacture due to the similarity of slabs.

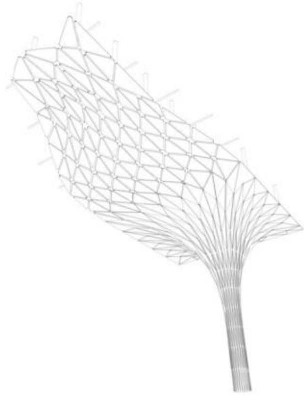

Figure 13: A ceiling consisting of several types of tiles of different sizes to form the Tessellated. (Chan, 2011)

V-5 Tiling

The process of tiling also referred to as 'tessellating,' involves developing figures or shapes that form a coherent plane without gaps or overlaps when assembled together. Such tiles may have any geometric shape provided they fit together, even if the tiles change in size and shape across the plane itself. The patterned, tiled surfaces found in architecture are directly analogous to the mesh patterns defined using digital tiling tools. These precedents required the configuration of myriad fragments to form an intricate yet uniform design. (DUNN, 2012)

Despite this, the cumulative result afforded considerable variation in terms of geometry, tone and overall image. One of the many advantages of digital design and fabrication methods is that they can effectively overcome the previous investment of time and provide ways in which patterns may be generated and optimized to gain maximum impact both visually and materially – especially concerning reducing waste. (DUNN, 2012)

Therefore, this method of making complex three-dimensional forms and surfaces from a kit of essentially two-dimensional components has enabled architects to overcome one of the greatest obstacles in fabricating this type of design. (DUNN, 2012)

Figure 14: Armstrong Lyra® PB Shapes panels with Suprafine® XM 9/16" suspension system.

As a result, designers can fabricate components with much more differentiation than hitherto. Combined, they may produce effects in aesthetic, material, and experiential terms that are much more transformative than the simple sum of their parts. (DUNN, 2012)

V-6 Triangulation:

Surfaces resulting from dividing surfaces into triangles to reach individuals of any complex curved shape, whether two-dimensional or three-dimensional. (Pfeifer, 2002)

This type of ceiling is considered one of the most common types, and it is very similar to mosaic surfaces, but the division here only into triangles without other shapes; most computer-aided engineering design programs mainly rely on this technique such as Nurbs to divide curved shapes and convert them into flat surfaces that can be produced easily. (Tasso Karkanis, 2001)

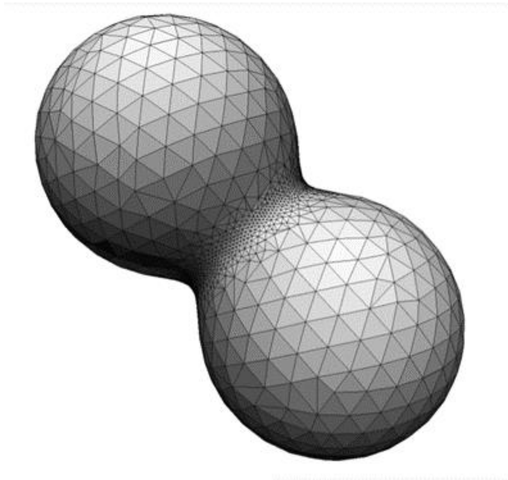

Figure 15: Divide the shape into equilateral triangles as much as possible (same previous source)

The shape and size of the triangles in the geometric figure may vary depending on the nature of the form. The curves' unit may sometimes lead to sharp three-dimensional curves to form small triangles that cannot be produced. The Bishop's designers may leave some spaces between the void to avoid unwanted triangles to reduce such problems.

Figure 16: Leave spaces between the triangles untreated (Pinterset, n.d.)

V-7 Forming

Formative processes have been discussed earlier, but the procedure of forming is relevant again here since it requires a particular approach in relation to the digital technologies that enable it. Forming is tooling through the generation of components from a form and is most readily applied to mass consumer products. It has been used to make such architectural elements as façade panels, detail components, and other hardware. On-site, forming is a long-established process for producing precast structural columns and beams, walls, panels, or even whole building zones such as circulation cores. Digital fabrication approaches the method similarly, requiring a mould or form usually created via CNC milling but occasionally uses rapid-prototyping techniques. The forming process produces positive and negative molds, also referred to as 'male' and 'female.' Positive molds are used for thermo- and vacuum molding. At the same time, negative molds may also facilitate casting and injection molding. Both types afford metal stamping and other comparable methods. Forming is an effective and relatively economical method of making a significant number of components. As a result, it is typical for a great deal of effort, time, and cost to fabricate the molds.

The forming process has considerable potential for architectural design since it may be utilized with various materials and be easily integrated with traditional and digital modes of making. Perhaps to an even greater degree than folding, this approach's key advantages relate to full-size fabrication, which makes it an effective bridge between digital design and production.

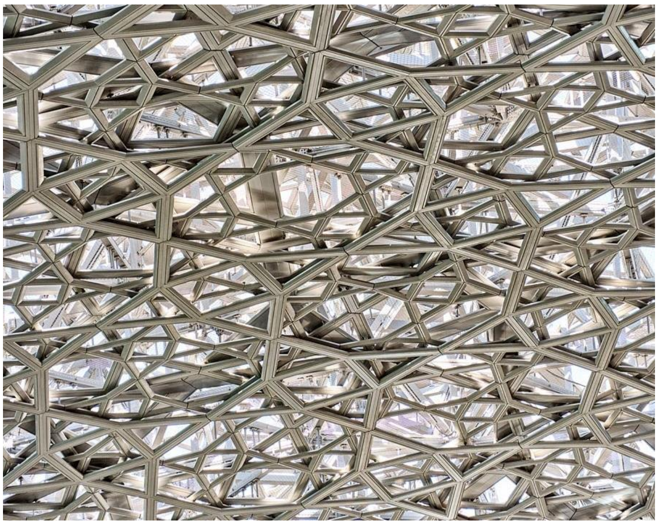

Figure 17: The intricate geometric patterns found in the dome interior at the Louvre Museum by architect Jean Nouvel, in Abu Dhabi, United Arab Emirates (Andrew Prokos Photography, n.d.)

VI. THE TECHNICAL CHARACTERISTICS OF SUSPENDED CEILINGS:

Each country and region has its own standard specifications, and this research will be dealt with according to the standard specifications set by The American Society for Testing Materials (ASTM), which are considered the most common, used and source used in many countries to write the standard specifications that are used.

The American Society for Testing Materials (ASTM) has established the standard classification for acoustic ceiling products by type, pattern, and specific ratings for acoustic performance, light reflectance, and fire safety (ASTM E1264-19, 2019).

Moreover, we will discuss these determinants in detail in addition to antibacterial performance, air quality, and humidity resistance, attempting to reach parameters that may (or may not apply) to the parameter ceiling.

VI-1 Format of Classification of the acoustical ceiling tile according to ASTM E 1264.

The ceiling classification shall conform to the below-mentioned format:

Type [Form]; Pattern; NRC or AC (specify); CAC; LR; Fire Class.

For example, a lightly textured, water felted mineral base ceiling with a painted finish, having an NRC 0.70, AC 190, CAC 39, LR 0.82, and a flame spread rating of 50 would be labeled as one of the following:

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. (ASTM E1264-19, 2019)

VI-2 Type & Pattern:

The Types:

The ASTM divided 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 (ASTM E1264-19, 2019).

Concerning the types of parametric ceilings, traditionally, ceilings can be manufactured from wood, metal ceiling, high-density gypsum fiberboard, and all of this material under type XX.

The Patterns:

Specifications indicated Acoustical ceilings might be one of or a combination of two or more of the many types of patterns like perforated, light, or heavily textured smooth of rough surface, and all ceiling types(modular and parametric) can contain one or more of these patterns.

VI-3 Acoustical Ratings:

At any point in a room, we hear a combination of sound that travels from the source directly to our ear and sound reflected from the walls and other obstructions. If reflections are so large that the sound level becomes uniform throughout the room, we have what is termed a diffuse acoustic field.

A specular reflection occurs when sound reflects off a hard polished surface, the same as with light. (BINGGELI, Building systems for interior designers, 2003)

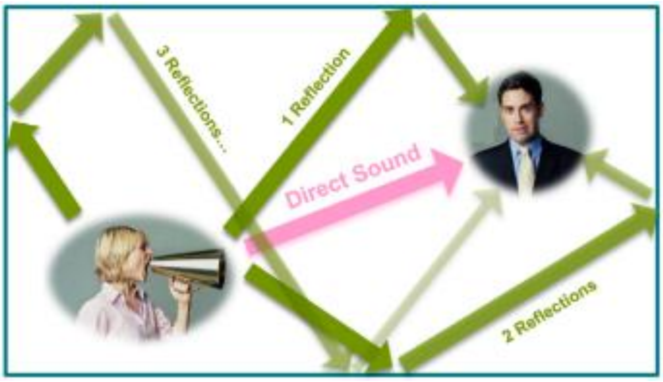

Figure 18: Reflections of sound through different surfaces (Source Researcher Training 2010)

VI-4 Noise Reduction Coefficient (NRC):

a single-digit rating derived from measured values of sound absorption coefficients following 11.7 of Test Method ASTM C 423. It calculates an estimate of the sound-absorbent property of acoustical material. (ASTM C634-13, 2021)

Rooms are constructed and furnished with a combination of materials, each along 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 frequencies, the absorption coefficients at 250, 500, 1000, and 2000 Hz are averaged together for the noise reduction coefficient (NRC). (BINGGELI, Building systems for interior designers, 2003)

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. (David Canning, 2015)

Test Specimen Ceiling Specimens for Absorption Coefficient:

The specimen must be a rectangle patch assembled from one or more pieces. An area of 6.69 m2 is customary and recommended, in shape 2.44 by 2.74 m. An area less than 5.57 m2 shall not be used, and extreme aspect ratios, such as long narrow strips, shall be avoided. (ASTM C423-17, 2017)

Mounting—Insofar as its acoustical properties are concerned, the specimen shall be mounted in a way that simulates actual installation. The types of mountings most commonly used are specified in Practices E 795. If a mounting fixture is used, it shall be removed from the reverberation room during the empty room tests unless it can be shown that the mounting fixture does not contribute to the empty room sound absorption. (ASTM C423-17, 2017)

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. (Rockfon North America, 2021)

Sabins are the sound absorption unit used for acoustic baffles, islands, and other three-dimensional sound absorbers placed or suspended inside rooms. Same as the previous reference

VI-5 Articulation Class (AC):

is the sum of the weighted sound attenuations in a series of 15 test bands (200 Hz to 5000 Hz). (ASTM E1110-06, 2019), Articulation Class (AC) indicates the ceiling's capability to attenuate speech that might reflect off the ceiling above partial-height cubicle walls in open office spaces. Same as the previous reference

Meaning that speech reflecting off the ceiling over the cubicle partition would be easier to understand, which means that the ceiling promotes speech privacy by attenuating the reflection above the cubicle partition. The ASTM E1110 and E1111 standards are used to measure AC. Same as the previous reference

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. (Rockfon North America, 2021)

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

The ASTM sets the standard for measuring the AC, related to heights and the area to be tested As shown in the Test Specimen in ASTM E 1111, indicated as the following: The ceiling to be tested shall cover the entire area of the laboratory facility or at least a 4.5 by 9 m (15 by 30 ft) area in a field test facility. Its nominal level shall be 2.75 m ± 50mm (9 ft 6 ± 2 in.) above the floor, and it shall be suspended from a flat structural slab or deck with a plenum depth of not less than 0.60 m (24 in.) with a preferred depth of 0.75 m (30 in.). (ASTM E1111 / E1111M-14, 2014)

In addition to The nominal ceiling level shall be defined as that of the exposed surface of a continuous flat ceiling, or of the lowest exposed surface of a nonflat ceiling. If, in a field test situation, the ceiling height and plenum conditions cannot be met, this test method may Used for assessment the test setup and may not be used to obtain general interzone attenuation data for the ceiling system. (ASTM E1111 / E1111M-14, 2014)

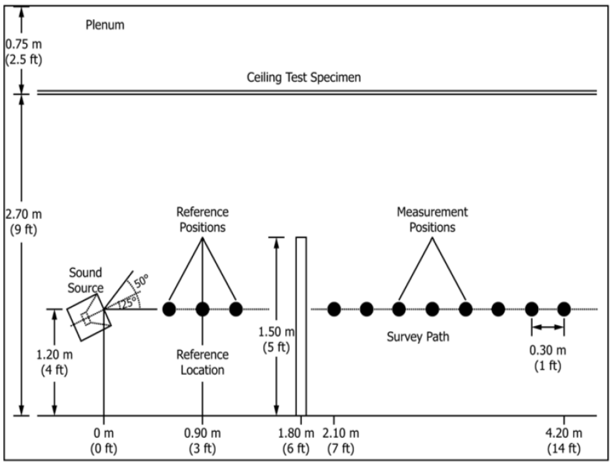

Figure 19: Ceiling test facility according to ASTM E 1111

It is evident from the previous two paragraphs that the parametric ceilings cannot meet this type of criteria, as it is difficult to test and confirm the results due to the difficulty of meeting the conditions of the tested sample.

VI-6 Ceiling Attenuation Class (CAC):

is a measure for valuing the ability of a ceiling system to prevent airborne sound transmission between neighboring closed areas such as offices via a shared plenum. (AWI, 2021)

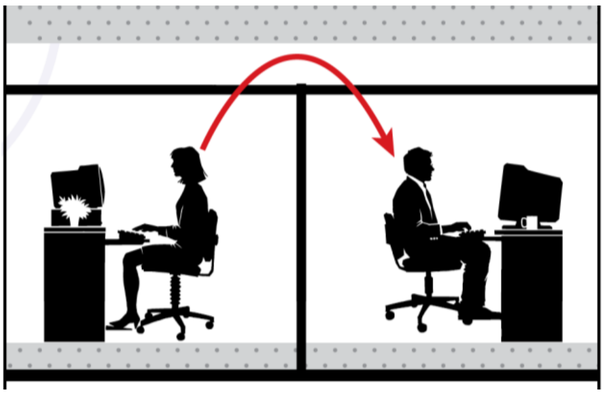
Figure 20: Sound transmission through a common plenum.

CAC does not apply to open offices. It should not be included in specifications for ceiling panels in large open spaces without walls. (Madaras G. , 2019, p. 18)

An acoustical ceiling may meet a

CAC rating, derived following Test Method E 1414 and Classification E 413. CAC values can vary from 5 to 55 decibels. (ASTM E1264-19, 2019)

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, which is challenging to achieve in parametric ceilings:

The Room and Plenum Construction:

- The rooms shall be rectangular in shape and cross-section. It is recommended that a structural discontinuity be provided close to the mid-point between the rooms to minimize flanking sound transmission; the total length of each sidewall, including the vibration break (if any), shall be 7.5 ± 1.5 m and the width of the room shall be 4.65 ± 0.23 m. The overall height shall be 3.65 ± 0.15 m. All dimensions shall be measured internally.
- The two rooms shall not differ in length by more than 15 %.
- Plenum Depth—The plenum depth shall be 760±25 mm at the separating wall. At other places within the room, the plenum depth tolerance may be relaxed to ±64 mm.
- Plenum Width— The plenum width shall be 4.3±0.02 m at the separating wall. At other points in the room, the plenum width should be the same as the full room width. The restriction in plenum width at the separating wall may be achieved through suitable pilasters installed either from floor to roof or from the level of the ceiling underside to the roof.

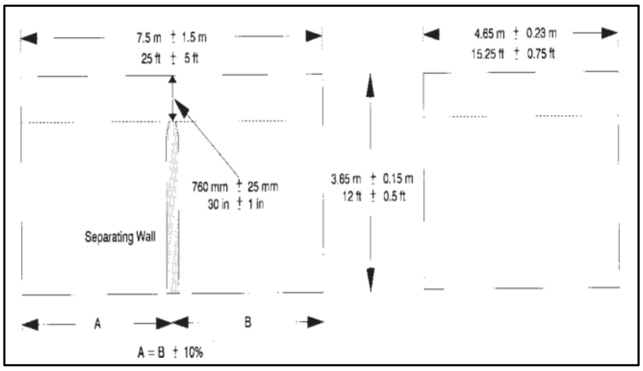

Figure 21: General Dimensions of the Test Room.

The area of the ceiling system under test shall equal the area formed by the room's length and width, less the following areas:

- The area of the supporting ledge around the perimeter,
- The area of the adapter cap when the ceiling is interrupted, and
- The area of any fillers as described in 8.1.
- The Acoustical Requirements:
- The walls, floor, doors, and roof should provide sufficient acoustical isolation to reduce external noise levels to no less than 10 dB below the lowest test signal level.
- The sound absorption in each of the rooms should be made as low as possible to achieve the best possible diffuse field condition. The average sound absorption coefficients of the floor and all vertical surfaces below the test ceiling should not exceed 0.1 at any of the octave band center frequencies given in the below table.
- All sidewalls of the plenum shall be lined with suitable sound-absorbing material not less than 76 mm (3 in.) thick. This material, shall when tested following Test Method C 423 in a Type A mounting, have random incidence sound absorption coefficients not less than those shown below:

Octave Band Center Frequency, Hz	125	250	500	1000	2000	4000
Absorption Coefficient	0.65	0.80	0.80	0.80	0.80	0.80

Table 1: the required sound absorption coefficients of the material which covers the plenum.

A suitable plenum lining has been found to be 6-in. thick. (ASTM E1414 / E1414M-21, 2021)

Achieving such a test on the project site is almost impossible due to the aforementioned factors, besides the following extra confirmations.

The actual performance in the field might differ considerably, particularly if the field plenum depth is not within limits specified in this test method or if the plenum space contains large ducts, beams, etc., or both. (ASTM E1414 / E1414M-21, 2021)

The ASTM C423 Appendix X2 (field test method suitable for obtaining decay rates and room sound absorption) clarified that when sound absorption measurements are made in a building in which the size and shape of the space are not under the operator's control, the approximation to a diffuse sound field is not likely to be very close. This should be considered when assessing the accuracy of measurements made under field conditions. (ASTM C423-17, 2017)

In addition, The test described in this appendix X2.1.2 is not acceptable for laboratory use or for measurement of the sound absorption and sound absorption coefficients of a specimen. (ASTM C423-17, 2017)

VI-7 Light Reflectance (LR):

An object is only visible because the eye receives some of the light that is reflected off it. If an object reflected no light, it would appear to us as a featureless black silhouette. The definition of black is the complete absence of all colors within the light spectrum. On the other hand, the definition of white is the equal presence of all colors within the light spectrum. Therefore, materials with a color that is not black or white must lie somewhere between these two bounding extremes. (Marsh, 2010)

benefits of High- Light Reflectance Ceilings:

Daylight and electrical lighting are the two primary sources of lighting in the workplace. A well-designed ceiling with high light reflectance enhances the room's overall illumination and lighting uniformity, directly affecting working comfort, wellbeing, and productivity. (Zentia, n.d.)

Knowing the color properties is helpful when coordinating colors or creating a mood, as it helps businesses, schools, and homes stay energy efficient; choosing a color with a more significant light reflectance value probably not require as much lighting or air conditioning as a color that soaks up light and warms quickly.) (Vogel, 2016)

- Light Reflectance ≥ 90% ⇒ 20% cost saving with indirect lighting
- Total building energy savings up to 11%
- 7% savings in cooling system energy
- High light reflectance ceilings contribute to LEED®, BREEAM, HQE, DGNB, and Ska credits by improving visual comfort (Zentia, n.d.)

Light Reflectance Value:

(LRV) measures the amount of visible and usable light that reflects from (or absorbs into) a painted surface. Simply put, LRV measures the percentage of light a paint color reflects. (Vogel, 2016)

LRV is measured on a level that ranges from zero (absolute black, absorbing all light and heat) to 100 percent (pure white, reflecting all light). Building and design experts use these measurements as guidelines to predict how light or dark a color will appear. (Vogel, 2016)

Real 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%. (Marsh, 2010)

The Americans with Disability Act Accessibility Guidelines (ADAAG) advises a 70% light reflectance value or greater for those with impaired vision, but it is not a strict condition. There are many color combinations in the 60-70% range that work well. (Vogel, 2016)

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

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
Aluminum, 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
Aluminum, anodized, matte	80 - 85
Lacquer, pure white	80 - 85
Aluminum, pure, highly polished	80 - 87
Silvered mirror, behind glass	80 - 88
Silver, highly polished	90 - 92
Body where all light is reflected	100

Table 2: Light-reflecting factor for some material. (The Engineering ToolBox, 2012)

Light Reflection Measurement:

The ASTM E1331 & E 1164 has defined the light reflection measurement method using a spectrophotometer or spectrocolorimeter with a hemispherical optical measuring system such as an integrating sphere. (ASTM E1331-15, 2019) (ASTM E1164-12(2017)e1, 2017)

When mentioning to building materials, the term reflectance is normally shown to mean hemispherical reflectance. This is the radiation's relative fraction that bounces back somewhere into the hemisphere whose zenith is usual to the surface plane and on the same side of the surface as the incident radiation source, as shown in the following figure. (Marsh, 2010)

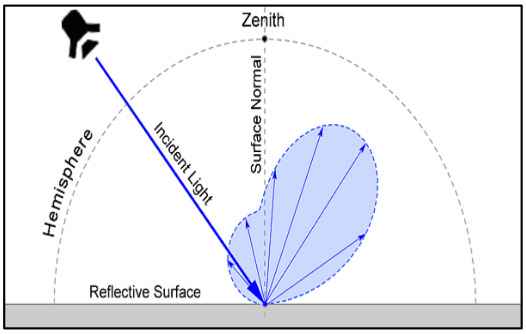

Figure 22: hemispheric reflection on the same side of the surface as the incident light.

Diffuse reflection:

Diffuse reflection happens when a surface is not smooth. If the surface roughness is similar to or larger than the light's wavelength, the rays will scatter in many directions. In diffuse reflection, the Reflection law is still applicable, however, the surface's angle is changing such that incoming parallel beams hit the various surface angles. (Carrier, 2016)

Parameters to be considered when applying diffuse reflectance spectroscopy consist of sample distance, spot size, and surface. (Carrier, 2016)

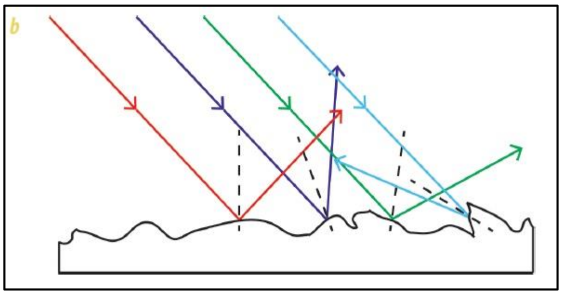

Figure 23: diffuse reflection. (Considerations for Diffuse Reflection Spectroscopy, 2016)

Sample distance:

Distance determines how much-reflected light can be gathered and forwarded back to the detector: if the light is divergent and the distance from the sample changes, a different amount of light is sent to the detector. If the distance changes, then more or less light could reach the detector. (Carrier, 2016)

Spot size:

Both the sample and the information needed must be considered to determine the appropriate spot size. Is the sample a large sheet roller or a fine powder? The entire area of interest is often illuminated, though this may not be possible for very large or very small samples. (Carrier, 2016)

With large samples, it may not be practical to illuminate the entire sample simultaneously. For example, a conveyor belt containing samples may be several feet wide, making it impossible to collect all of the reflected light. Smaller, representative spot sizes may be chosen, or the measurement spots moved so that most of the sample on the belt can be scanned sufficiently. In these cases, the operator must decide if and how many scanned smaller sample sections adequately represent the whole. Another option is to move the measurement spot(s) to allow more areas of the sample to be measured, and a map of the measurement spots of the sample can be created. Either way, the measurement spot size must illuminate a representative portion of the sample. (Carrier, 2016)

Surface:

The ideal sample surface is a macroscopically flat surface. The material of interest should be spread uniformly within the inspection area to create a homogeneous hemisphere of backscatter (black hemisphere in Figure 10a). As the surface begins to angle relative to the light source, the sphere of backscatter changes (Figure 10b). Therefore, it is much simpler to create a setup so that the light reflecting back to the detector has a constant distance and constant angle. (Carrier, 2016)

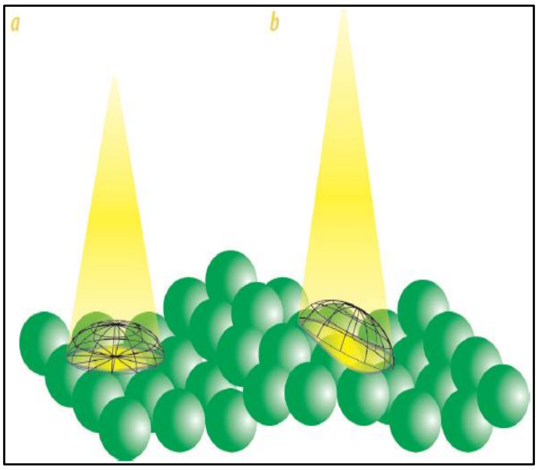

Figure 24: Effects of illuminating a nonflat surface. (Carrier, 2016)

The relationship summary between light reflectance & parametric ceiling:

The perfect reflecting ceiling that neither absorbs nor transmits light but reflects light in a diffused manner with the radiance of the reflecting surface being the same for all reflecting angles, regardless of the angular distribution of the incident light. (ASTM E1477-98A(2017)e1, 2017)

Drilled acoustical ceiling materials with large diameter holes of appreciable depth have a high reflectance from the tile surface and a low reflectance from the hole location. Fissured tiles provide a similar but less exaggerated condition. In addition, fissured tiles and striated tiles have reflectance that depends on the angle of incidence of the light relative to the general direction of the surface features. This test method provides a suitable average over these surface features. (ASTM E1477-98A(2017)e1, 2017)

A curved or irregular surface has two main issues: the changing distance and the light detected. The changing distance causes the issues mentioned above. However, the larger issue is that it alters what reflectance is picked up where, and the reflectivity of the sample will seem to change, depending on the angle of illumination and detection. A curved or irregular surface often requires a much more complicated setup to account for the changing macroscopic angles. (Carrier, 2016)

VI-7 Fire Class/Surface Burning Characteristics :

Death due to fire: Smoke inhalation accounts for more than 80% of fire-related fatalities, most of which result from residential fires. The pathophysiology of smoke inhalation is multifactorial and involves additive or synergistic toxicity from hypoxia, thermal injury, and numerous chemical toxins (e.g., carbon monoxide, hydrogen cyanide, irritant gases).

Asphyxia is the most common cause of death in in patients with smoke inhalation (i.e., tissue hypoxia and consequent acidosis). The carboxyhemoglobin fraction is elevated in virtually all patients exhibiting signs and symptoms of asphyxia. (Linden, 2007)

The Test Method: Acoustical ceiling products may be classified by flame spread, and smoke-developed indexes tested following test method ASTM E 84. (ASTM E1264-19, 2019) this test method aims to define the relative burning behavior of the material by observing the flame spread along with the specimen in the ceiling place with the surface to be calculated exposed face down to the ignition source. However, there is not necessarily a relationship between these two measurements. (ASTM E84-21, 2021)

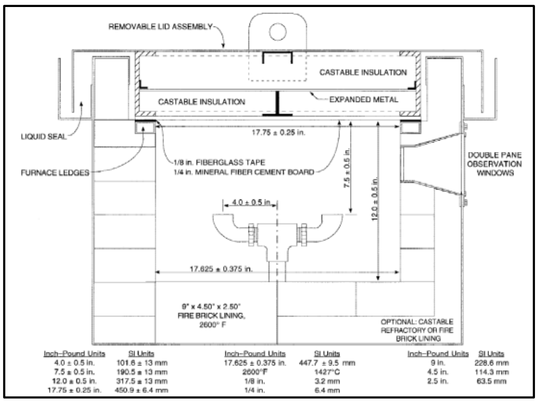

Figure 25: Test Furnace Showing Critical Dimensions (Not a Construction Drawing)

Figure 26: specimen in the ceiling position with the surface to be evaluated exposed face down to the ignition source. (Crimi, 2018)

There are three classes of reporting, Class A, B, and C; the numbers range of flame spread from 25, 75, and 200.

Classes A, B, and C are equivalent to Classes I, II, and III of various building code authorities. (ASTM E1264-19, 2019)

test Method E 84 results have generally shown performance similar to that observed during accidental building fires for some materials and exposure. However, it should be emphasized that this test method intends to provide only comparative classifications. (ASTM E84-21, 2021)

Composite assemblies or panels using metal or mineral facings and combustible interior cores, and which remain essentially impermeable to flame throughout the test period, may not be completely evaluated for surface burning behavior by this method since the interior cores are not fully challenged. (ASTM E84-21, 2021)

Some materials, such as composites, may delaminate during the test. This may cause two possible responses; the material may expose two or more surfaces to the flame increasing the Flame Spread Index (FSI); the material may sag or drop one end into the fire chamber impeding further flame spread. (ASTM E84-21, 2021)

Some materials, such as cellular plastics and thermoplastic and thermosetting materials, may be difficult to evaluate. Thermoplastic and thermosetting materials not mechanically fastened will often fall to the tunnel floor and usually receive relatively low FSI (10). (ASTM E84-21, 2021)

The materials described above, those that drip, melt, delaminate, draw away from the fire, or require artificial support, present unique problems 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 with increasing area of exposure of the material and increasing intensity of the fire exposure. The outcome, therefore, may not be indicative of their performance if evaluated under large-scale test procedures. Alternative means of testing may be necessary to evaluate some of these materials fully. (ASTM E84-21, 2021)

According to the information mentioned earlier, the test ASTM E 84 can apply to all types of suspended material (modular and parametric) even 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).

VI-8 Fire Tests of Building Construction and Materials

Although the ASTM has not specified the Fire Tests of Building Construction and Materials as one of the ratings, 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 has defined fire resistance as the property of a material or assemblage to withstand fire or give protection from it (ASTM E176-18ae1, 2018)

The ASTM E 119 standard for the test methods described in this fire-test-response standard applies to assemblies. This procedure applies to floor and roof assemblies with or without attached, furred, or suspended ceilings and requires application of fire exposure to the underside of the specimen under test. (ASTM E119-19, 2019)

It is worth noting here that this test applies to medallion ceilings and does not apply to parametric ceilings for the following reasons:

This standard is used to measure and define the response of materials, products, or assemblies to heat and flame under controlled conditions but does not by itself incorporate all factors required for fire hazard or fire risk assessment of the materials, products, or assemblies under actual fire conditions. (ASTM E119-19, 2019)

The test standard does not provide the following: Full information about the performance of assemblies constructed with components or lengths other than those tested. Moreover, The effect of fire endurance of conventional openings in the assembly is electrical receptacle outlets, plumbing pipe, And other ingredients, unless expressly provided for in the construction tested. (ASTM E119-19, 2019)

The test specimen shall be truly representative of the construction for which classification is desired, materials, workmanship, and details such as dimensions of parts, and shall be built under conditions representative of those obtained as practically applied in building construction and operation. The physical properties of the materials and ingredients used in the test specimen shall be determined and recorded. (ASTM E119-19, 2019)

Size and Characteristics of specimen: the area exposed to fire shall be not less than 16 m2 with neither dimension less than 3.7 m. (ASTM E119-19, 2019)

Structural members, if a part of the construction under test, shall lie within the combustion chamber and have a side clearance of not less than 203 mm from its walls. (ASTM E119-19, 2019)

All of the above reasons cannot often be applied literally in parametric designs due to the complex and intricate designs that contain many openings, voids, and levels.

VII. SUMMARY:

Technical characteristics	ASTM Standard	The definition	Applicable	Justification
TYPE	E 1264	The ASTM divides the acoustic suspended ceilings according to the raw material made of and the manufacturing method.	Yes	Parametric ceilings can be manufactured from wood, metal ceiling, high-density gypsum fiberboard, and this material under type XX.
PATTERN	E 1264	Acoustical ceilings may be a combination of one or more patterns, like perforated or textured.	Yes	The parametric ceiling can contain one or more patterns, like perforated or textured.
NOISE REDUCTION COEFFICIENT (NRC)	C 423, E 795, C 634	A single-number rating derived from measured values of sound absorption coefficients following 11.7 of Test Method ASTM C 423.	No	The NRC is not used to define the absorption provided by individual sound absorbers placed into a room or suspended over space, such as ceiling baffles and islands.
ARTICULATION CLASS (AC)	E 1110, E 1111, C 634	Indicates the ceiling's ability to attenuate speech that could reflect off the ceiling over partial-height cubicle walls in open office spaces	No	The ASTM sets the standard for measuring the AC as the following: 1- The room dimension (area & height) and minimum plenum depth. 2- The exposed surface of a continuous flat ceiling or the lowest exposed surface of a nonflat ceiling. 3- The field test method may be used to evaluate the test setup and may not be used to obtain general Interzone attenuation data for the ceiling system.
CEILING ATTENUATION CLASS (CAC)	E 1414, C 634	A measure for rating the performance of a ceiling system as a barrier to airborne sound transmission	No	1- The Room and Plenum Construction. 2- The Acoustical Requirements. 3- The field test method is

		through a common plenum between adjacent closed spaces such as offices		not acceptable for laboratory use.
LIGHT REFLECTANCE (LR)	E 1331, E 1477	A measure of the amount of visible and usable light reflecting (percentage) from (or absorbs into) a painted surface.	No	1- Changing distance and the light detected in the curved or irregular ceiling. 2- Curved or irregular ceiling alters what reflectance is picked up where, and the sample's reflectivity will seem to change. 3- A curved or irregular surface often requires a much more complicated setup to account for the changing macroscopic angles.
FIRE REACTION	E 84	Determine the relative burning behavior of the material by observing the flame spread along with the specimen in the ceiling position with the surface to be evaluated exposed face down to the ignition source	Yes	It can apply to all types of suspended material even the size of the panel is less than 508 mm
FIRE RESISTANCE	E 119	The property of a material or assemblage to withstand fire or give protection from it	No	1- it does not by itself incorporate all factors required for fire hazard or fire risk assessment of the materials, products, or assemblies under actual fire conditions. 2- The test standard does not provide complete information about the performance of assemblies constructed with components or lengths other than those tested. 3- The effect of fire endurance of conventional openings in the assembly is electrical receptacle

				outlets, plumbing pipe, And other ingredients unless expressly provided for in the construction tested. 4- The test specimen shall be truly representative of the construction for which classification is desired. 5- The area exposed to fire shall be not less than 16 m2 with neither dimension less than 3.7 m. 6- Structural members: if a part of the construction is under test, it shall lie within the combustion chamber and have a side clearance of not less than 203 mm from its walls.

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

VIII.CONCLUSION:

Parametric design is a new approach to modernist architecture. It allows architects to make changes to ceilings automatically, reducing the time and effort required to implement and manually perform these modifications. Designers can take human error out of the equation and minimize manual repetitions.

The modeling and the scripting environment allow architects and designers to experiment with the structure's digital fabric to recreate the structure in real life. Architects could adjust each panel's size and shape to change the shape of the ceiling's various details.

Also, the results of the presented study have shown the measured technical foundations and rules for designing parametric ceilings. It also intended to establish a detailed understanding of the suspended ceiling performances. And it has shown the types of parametric ceiling according to the strategic approach of parametric design.

Reaching to the results of the modular ceilings tests can be generalized to all the quantities produced from the same product that carries the same ingredients at any time, and accordingly, a data-sheet can be issued for architects to use in their projects as a reference with stable scientific evidence.

The further outcome that most of the ceiling performance of the architectural spaces, represented in acoustics, vision, in addition to fire resistance, cannot be applied in general to parametric ceilings due to the difference of many unique parameters, whether the test environment, the shape, and size of the test specimen or the direction of its installation.

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