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1. Ⓐ Ⓑ Ⓒ Ⓓ	3. Ⓐ Ⓑ Ⓒ Ⓓ	5. Ⓐ Ⓑ Ⓒ Ⓓ	7. Ⓐ Ⓑ Ⓒ Ⓓ	9. Ⓐ Ⓑ Ⓒ Ⓓ
2. Ⓐ Ⓑ Ⓒ Ⓓ	4. Ⓐ Ⓑ Ⓒ Ⓓ	6. Ⓐ Ⓑ Ⓒ Ⓓ	8. Ⓐ Ⓑ Ⓒ Ⓓ	10. Ⓐ Ⓑ Ⓒ Ⓓ

Designing Buildings for Earthquakes | *Course #*: AIAPDH278

1. Ⓐ Ⓑ Ⓒ Ⓓ	5. Ⓐ Ⓑ Ⓒ Ⓓ	9. Ⓐ Ⓑ Ⓒ Ⓓ	13. Ⓐ Ⓑ Ⓒ Ⓓ	17. Ⓐ Ⓑ Ⓒ Ⓓ
2. Ⓐ Ⓑ Ⓒ Ⓓ	6. Ⓐ Ⓑ Ⓒ Ⓓ	10. Ⓐ Ⓑ Ⓒ Ⓓ	14. Ⓐ Ⓑ Ⓒ Ⓓ	18. Ⓐ Ⓑ Ⓒ Ⓓ
3. Ⓐ Ⓑ Ⓒ Ⓓ	7. Ⓐ Ⓑ Ⓒ Ⓓ	11. Ⓐ Ⓑ Ⓒ Ⓓ	15. Ⓐ Ⓑ Ⓒ Ⓓ	19. Ⓐ Ⓑ Ⓒ Ⓓ
4. Ⓐ Ⓑ Ⓒ Ⓓ	8. Ⓐ Ⓑ Ⓒ Ⓓ	12. Ⓐ Ⓑ Ⓒ Ⓓ	16. Ⓐ Ⓑ Ⓒ Ⓓ	20. Ⓐ Ⓑ Ⓒ Ⓓ

Biomimicry and Regenerative Design | *Course #*: AIAPDH275

1. Ⓐ Ⓑ Ⓒ Ⓓ	6. Ⓐ Ⓑ Ⓒ Ⓓ	11. Ⓐ Ⓑ Ⓒ Ⓓ	16. Ⓐ Ⓑ Ⓒ Ⓓ	21. Ⓐ Ⓑ Ⓒ Ⓓ
2. Ⓐ Ⓑ Ⓒ Ⓓ	7. Ⓐ Ⓑ Ⓒ Ⓓ	12. Ⓐ Ⓑ Ⓒ Ⓓ	17. Ⓐ Ⓑ Ⓒ Ⓓ	22. Ⓐ Ⓑ Ⓒ Ⓓ
3. Ⓐ Ⓑ Ⓒ Ⓓ	8. Ⓐ Ⓑ Ⓒ Ⓓ	13. Ⓐ Ⓑ Ⓒ Ⓓ	18. Ⓐ Ⓑ Ⓒ Ⓓ	23. Ⓐ Ⓑ Ⓒ Ⓓ
4. Ⓐ Ⓑ Ⓒ Ⓓ	9. Ⓐ Ⓑ Ⓒ Ⓓ	14. Ⓐ Ⓑ Ⓒ Ⓓ	19. Ⓐ Ⓑ Ⓒ Ⓓ	24. Ⓐ Ⓑ Ⓒ Ⓓ
5. Ⓐ Ⓑ Ⓒ Ⓓ	10. Ⓐ Ⓑ Ⓒ Ⓓ	15. Ⓐ Ⓑ Ⓒ Ⓓ	20. Ⓐ Ⓑ Ⓒ Ⓓ	25. Ⓐ Ⓑ Ⓒ Ⓓ

Integrating Generative AI into the Architectural Workflow | *Course #*: AIAPDH276

1. Ⓐ Ⓑ Ⓒ Ⓓ	6. Ⓐ Ⓑ Ⓒ Ⓓ	11. Ⓐ Ⓑ Ⓒ Ⓓ	16. Ⓐ Ⓑ Ⓒ Ⓓ	21. Ⓐ Ⓑ Ⓒ Ⓓ
2. Ⓐ Ⓑ Ⓒ Ⓓ	7. Ⓐ Ⓑ Ⓒ Ⓓ	12. Ⓐ Ⓑ Ⓒ Ⓓ	17. Ⓐ Ⓑ Ⓒ Ⓓ	22. Ⓐ Ⓑ Ⓒ Ⓓ
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ACCESSIBLE ASSEMBLY AREAS

Course Number: **AIAPDH277**

Using a scale from 1 to 5 where 1 is "Poor" and 5 is "Excellent," please evaluate the course in the following areas: (circle one number per question)

	Poor				Excellent
1. Overall satisfaction with this course	1	2	3	4	5
2. Course learning objectives clearly stated and met:	1	2	3	4	5
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5. Quality of course content:	1	2	3	4	5
6. Applicability/value of new knowledge, ideas or information:	1	2	3	4	5

DESIGNING BUILDINGS FOR EARTHQUAKES

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	Poor				Excellent
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2. Course learning objectives clearly stated and met:	1	2	3	4	5
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Course Number: **AIAPDH275**

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	Poor				Excellent
1. Overall satisfaction with this course	1	2	3	4	5
2. Course learning objectives clearly stated and met:	1	2	3	4	5
3. Satisfaction with the format of this course:	1	2	3	4	5
4. Met overall personal objectives for attending:	1	2	3	4	5
5. Quality of course content:	1	2	3	4	5
6. Applicability/value of new knowledge, ideas or information:	1	2	3	4	5

INTEGRATING GENERATIVE AI INTO THE ARCHITECTURAL WORKFLOW

Course Number: **AIAPDH276**

Using a scale from 1 to 5 where 1 is "Poor" and 5 is "Excellent," please evaluate the course in the following areas: (circle one number per question)

	Poor				Excellent
1. Overall satisfaction with this course	1	2	3	4	5
2. Course learning objectives clearly stated and met:	1	2	3	4	5
3. Satisfaction with the format of this course:	1	2	3	4	5
4. Met overall personal objectives for attending:	1	2	3	4	5
5. Quality of course content:	1	2	3	4	5
6. Applicability/value of new knowledge, ideas or information:	1	2	3	4	5

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ACCESSIBLE ASSEMBLY AREAS

Course #: AIAPDH277
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ACCESSIBLE ASSEMBLY AREAS
FINAL EXAM

1. **If there is a luxury box at an NFL stadium that has 52 fixed seats, how many wheelchair spaces must be provided within that luxury box?**
   A. 1
   B. 2
   C. 3
   D. 4

2. **How many wheelchair spaces are required in the team seating area of a high school soccer field?**
   A. 0
   B. 1
   C. 2
   D. It depends on the capacity of the team seating area.

3. **What percent of the total number of aisle seats must be accessible for those who have a hard time walking?**
   A. 2%
   B. 5%
   C. 10%
   D. None

4. **How many seats must a public entity make available for purchase in the same row that are contiguous with the wheelchair space?**
   A. 1
   B. 2
   C. 3
   D. 4

5. **Which of the following statements is true for restaurants?**
   A. 5 percent of dining surfaces must be accessible.
   B. The tops of dining surfaces must be between 28 and 34 inches above the ground.
   C. 50 percent of self-service shelves must be within the accessible reach ranges.
   D. All of the above.

6. **How many receivers are required if the assembly area has 533 seats?**
   A. 2
   B. 20
   C. 21
   D. 35

7. **What is the required width of a single wheelchair space?**
   A. 30
   B. 33”
   C. 36”
   D. 48”

8. **The shoulder alignment point of a companion seat is measured __ inches from the wheelchair space’s front edge.**
   A. 30”
   B. 36”
   C. 48”
   D. 60”

9. **Which of the following benches would meet the size requirements for an accessible bench going in a fitting room?**
   A. 16 inches deep x 42 inches long
   B. 18 inches deep x 36 inches long
   C. 20 inches deep x 36 inches long
   D. 24 inches deep x 48 inches long

10. **In the case study presented, how many seats were in the lecture hall?**
    A. Between 101 and 150
    B. Between 151 and 200
    C. Between 201 and 250
    D. The case study did not include a lecture hall.

ACCESSIBLE ASSEMBLY AREAS

Course Description

The *2024 International Building Code* defines assembly occupancies as 'the use of a building or structure, or a portion thereof, for the gathering of persons for purposes such as civic, social, or religious functions; recreation, food or drink consumption, or awaiting transportation'. Examples include restaurants, theaters, churches, and arenas. This course covers what must be accessible within assembly occupancies and how to make those elements accessible. A case study provides good and bad examples of accessibility for an assembly occupancy.

Learning Objectives

Learning objectives include the following.

1. Recognize an assembly occupancy.
2. Identify which elements within an assembly occupancy must be accessible per the scoping requirements outlined in Chapter 2 of the *ADA*.
3. Understand how to design accessible elements for assembly occupancies within the perimeters of the *ADA*.
4. Observe a case study of a constructed assembly occupancy and understand how to apply the *ADA Standards* to note accessible and inaccessible design features.

COURSE

The Americans with Disabilities Act (ADA) was signed into law in 1990. Even though that was more than thirty-five years ago, many design professionals and owners still have questions about what needs to be accessible and how to make those elements accessible. This course answers those questions for assembly occupancies.

Assembly Occupancy Defined

Assembly occupancies are one of the most common building occupancy types. The *2024 International Building Code* defines assembly occupancies as 'the use of a building or structure, or a portion thereof, for the gathering of persons for purposes such as civic, social, or religious functions; recreation, food or drink consumption, or awaiting transportation'. There are five different assembly groups defined by the code. Group A-1 occupancy includes uses with fixed seating, such as motion picture theaters, symphony/concert halls, television and radio studios with audiences, and theaters. Group A-2 occupancy is used for food/drink consumption. They include banquet halls, gaming areas of casinos, nightclubs, restaurants, and other dining facilities, and bars. Group A-3 occupancy is other assembly occupancies intended for worship, recreation, or amusement. Amusement arcades, art galleries, bowling alleys, community halls, courtrooms, dance halls, exhibition halls, funeral parlors, greenhouses, gymnasiums, indoor swimming pools without spectator seating, indoor tennis courts without spectator seating, lecture halls, libraries, museums, places of religious worship, pool and billiard parlors, and waiting areas in transportation terminals are considered Group A-3. Group A-4 occupancy is assembly areas intended for viewing indoor activities, such as arenas, skating rinks, swimming pools, and tennis courts. The final Group A-5 occupancy is assembly areas intended for viewing outdoor activities, such as amusement park structures, bleachers, grandstands, and stadiums.

Now that we know what constitutes an assembly occupancy, how do we know what must be accessible within it? The *2010 ADA Standards for Accessible Design*, or *ADA Standards*, for short, tells you what must be accessible in Chapter 2. It contains the scoping requirements and answers the following questions.

1. What elements of a building need to be accessible?
2. How many of those elements must be accessible?
3. Are there any exceptions to those requirements?

In this course, the *italic* numbers in parentheses list the referenced *ADA Standards* section numbers. All images are taken from the *2010 ADA Standards for Accessible Design* unless noted otherwise. A free downloadable version may be found at www.ada.gov. Remember that the Administrative Authority for local jurisdictions can modify the provisions and interpretations, so always check with the local governing authority for their specific requirements.

Scoping Requirements

Accessible Seating Numbers

Section 221, Section 35.151 of CFR Part 35, and *Subpart D of 28 CFR Part 36* provide the scoping requirements for assembly areas. One of the only items addressed specifically for assembly areas in the scoping requirements of the *ADA Standards* is accessible seating. The number of wheelchair spaces is based on the total number of seats provided in the assembly area. *Table 221.2.1.1* provides those amounts. The wheelchair seats for each individual suite or box at stadiums are calculated separately. (*221.2.1.2*) So, if there is a luxury box at an NFL stadium that has 28 fixed seats, no less than two (2) wheelchair spaces must be provided within that luxury box.

Table 221.2.1.1 Number of Wheelchair Spaces in Assembly Areas

NUMBER OF SEATS	MINIMUM NUMBER OF REQUIRED WHEELCHAIR SPACES
4 to 25	1
26 to 50	2
51 to 150	4
151 to 300	5
301 to 500	6
501 to 5000	6, plus 1 for each 150, or fraction thereof, between 501 through 5000
5001 and over	36, plus 1 for each 200, or fraction thereof, over 5000

For boxes at performing arts centers, the number of wheelchair spaces is calculated based on the total number of seats across all boxes. (*221.2.1.3*) The required wheelchair spaces must be dispersed among twenty percent (20%) of the boxes provided. For example, a performing arts center at a university has five (5) boxes with twenty (20) seats each. There are one hundred (100) box seats total, so four (4) wheelchair spaces are required in the boxes. At least one (1) box must have wheelchair seats. (.20 x 5 = 1)

Team Seating

Team seating areas are NOT exempt from having wheelchair spaces. No less than one (1) wheelchair space must be provided in each team seating area of sport activity. (*221.2.1.4*) If a player is injured and requires the use of a wheelchair, they should not be excluded from sitting with their team, even if they cannot play. There may be staff needing accommodations, as well.

Wheelchair Spaces

One specific requirement in the *ADA Standards* is that wheelchair spaces must be an integral part of the seating plan. (*221.2.2*) The wheelchair spaces and their associated companion seats cannot be located outside of the defined seating areas of the standard seats. At least one companion seat must be provided for each required wheelchair space. (*221.3*)

Another requirement is that the lines of sight are dispersed. (*221.2.3*) Spectators must be offered options for seating locations and viewing angles. The wheelchair space and companion seat options must be substantially equivalent to, or better than, those provided to all other spectators. (This does not apply to wheelchair spaces at team seating areas.) The dispersion requirement includes both horizontal and vertical dispersion. There are exceptions for assembly areas with 300 or fewer

seats. If the wheelchair and companion seats are positioned within the 2nd or 3rd quartile of the total row length, further horizontal dispersion is not required in assembly areas with 300 or fewer seats. However, if there is not enough length to position all required wheelchair and companion seats within the 2nd or 3rd quartile, those that do not fit may be placed in the 1st or 4th quartile of the row. (*221.2.3.1*) If vertical viewing angles for wheelchair and companion seats are equal to or better than the average viewing angle in an assembly area with 300 or fewer seats, vertical dispersion is not required. Bleachers only require wheelchair spaces on the same row as the point of entry, such as cross aisles, concourses, vomitories, and entrance ramps and stairs to the seating. (*221.2.3.2*)

Please note that in assembly areas with fixed seating that are required to have wheelchair seats, an accessible route is not required to the fixed seating where there are no accessible wheelchair spaces. (*206.2.4, Exception 2*)

Companion Seats

In addition to providing wheelchair seats and companion seats, 5 percent of the total number of aisle seats must be accessible and located near accessible routes for those who have a hard time walking. (*221.4*)

Lawn Seats

Any lawn seats and exterior overflow seating areas without fixed seating must be connected to an accessible route. (*221.5*)

Additional Code of Federal Regulations Requirements

§35.151(g) of 28 CFR Part 35 and Subpart D of *28 CFR Part 36, §36.406 (f)* outlines a few extra requirements for assembly areas.

(1) In stadiums, arenas, and grandstands, wheelchair spaces and companion seats are dispersed to all levels that include seating served by an accessible route;

(2) In assembly areas that are required to horizontally disperse wheelchair spaces and companion seats by section 221.2.3.1 of the 2010 Standards and that have seating encircling, in whole or in part, a field of play or performance, wheelchair spaces and companion seats are dispersed around that field of play or performance area;

(3) Wheelchair spaces and companion seats are not located on (or obstructed by) temporary platforms or other movable structures, except that when an entire seating section is placed on temporary platforms or other movable structures in an area where fixed seating is not provided, in order to increase seating for an event, wheelchair spaces and companion seats may be placed in that section. When wheelchair spaces and companion seats are not required to accommodate persons eligible for those spaces and seats, individual, removable seats may be placed in those spaces and seats;

(4) In stadium-style movie theaters, wheelchair spaces and companion seats are located on a riser or cross-aisle in the stadium section that satisfies at least one of the following criteria–

  (i) It is located within the rear 60% of the seats provided in an auditorium; or

  (ii) It is located within the area of an auditorium in which the vertical viewing angles (as measured to the top of the screen) are from the 40th to the 100th percentile of vertical viewing angles for all seats as ranked from the seats in the first row (1st percentile) to seats in the back row (100th percentile).

§35.138(d) of 28 CFR Part 35 and 28 CFR Part 36, §36.302 (f)(4)(i) expands to include ticketing requirements that affect the design of rows for accessible wheelchair seats. A wheelchair space must have an additional three (3) contiguous seats in the same row available for purchase.

Purchasing multiple tickets.

(1) ***General.*** For each ticket for a wheelchair space purchased by an individual with a disability or a third-party purchasing such a ticket at his or her request, a public entity shall make available for purchase three additional tickets for seats in the same row that are contiguous with the wheelchair space, provided that at the time of purchase there are three such seats available. A public entity is not required to provide more than three contiguous seats for each wheelchair space. Such seats may include wheelchair spaces.

(2) ***Insufficient additional contiguous seats available.*** If patrons are allowed to purchase at least four tickets, and there are fewer than three such additional contiguous seat tickets available for purchase, a public entity shall offer the next highest number of such seat tickets available for purchase and shall make up the difference by offering tickets for sale for seats that are as close as possible to the accessible seats.

(3) ***Sales limited to less than four tickets.*** If a public entity limits sales of tickets to fewer than four seats per patron, then the public entity is only obligated to offer as many seats to patrons with disabilities, including the ticket for the wheelchair space, as it would offer to patrons without disabilities.

(4) ***Maximum number of tickets patrons may purchase exceeds four.*** If patrons are allowed to purchase more than four tickets, a public entity shall allow patrons with disabilities to purchase up to the same number of tickets, including the ticket for the wheelchair space.

(5) ***Group sales.*** If a group includes one or more individuals who need to use accessible seating because of a mobility disability or because their disability requires the use of the accessible features that are provided in accessible seating, the group shall be placed in a seating area with accessible seating so that, if possible, the group can sit together. If it is necessary to divide the group, it should be divided so that the individuals in the group who use wheelchairs are not isolated from their group.

Dressing, Fitting, and Locker Rooms

Accompanying many assembly occupancies are dressing, fitting, and locker rooms. The scoping requirements for those spaces may be found in *Section 222*. At least 5 percent must be accessible. The 5 percent rule applies to each type of use within each group of rooms that are near each other. It is not 5 percent of the total number of dressing, fitting, or locker rooms within the building or on the site.

Performance Areas

If there is a circulation path directly from the performance area to a seating area, there must also be an accessible route that directly connects both. (*206.2.6*) An accessible route must also connect performance areas to ancillary areas that are used by performers unless exempted elsewhere in the code. The exceptions that may apply are the ones noted in *Section 206.2.3*. If the performance area is in a private building that is less than three stories or that has less than 3000 square feet per story, it could be exempt from needing an accessible route to it. If a two-story public building has a private story with an occupant load of five or fewer people, the low-occupancy story is not required to have an accessible route to it. Other exceptions involve detention facilities, residential facilities, transient lodging, air traffic control towers, and historic buildings.

Assistive Listening Systems

Another requirement for assembly areas is that where audible communication is necessary to the use of the space, then an assistive listening system must be provided unless audio amplification is not provided (other than in courtrooms). Receivers must be provided for assistive listening systems in each assembly area per *Table 219.3*. At least two receivers or twenty-five (25) percent of the receivers, whichever is greater, must be hearing-aid compatible. The number of

receivers can be based on the total number of seats in all of the assembly areas combined if they are under the same management and usable with all systems. Induction loop assistive listening systems do not need to be hearing-aid compatible. (*219*)

Table 219.3 Receivers for Assistive Listening Systems

CAPACITY OF SEATING IN ASSEMBLY AREA	MINIMUM NUMBER OF REQUIRED RECEIVERS	MINIMUM NUMBER OF REQUIRED RECEIVERS REQUIRED TO BE HEARING–AID COMPATIBLE
50 or less	2	2
51 to 200	2, plus 1 per 25 seats over 50 seats [1]	2
201 to 500	2, plus 1 per 25 seats over 50 seats [1]	1 per 4 receivers [1]
501 to 1000	20, plus 1 per 33 seats over 500 seats [1]	1 per 4 receivers [1]
1001 to 2000	35, plus 1 per 50 seats over 1000 seats [1]	1 per 4 receivers [1]
2001 and over	55, plus 1 per 100 seats over 2000 seats [1]	1 per 4 receivers [1]

1. Or fraction thereof.

Restaurants, Bars, and Other Dining Facilities

Group A-2 occupancies include restaurants, bars, and other dining facilities. *Section 206.2.5* requires that an accessible route be provided to all dining areas, including raised or sunken dining areas, and outdoor dining areas. There are a few exceptions. If a mezzanine is not required to have an accessible route, it has less than 25 percent of the total area for seating, and the same décor and services are provided in an accessible area, an accessible route is not required to the mezzanine dining area. If a space is being altered, the raised or sunken dining areas do not have to be made accessible if the same services and décor are provided in accessible dining areas. The tiered dining areas that are required to be accessible in sports facilities only require accessible routes to 25 percent of the dining areas as long as the same services are provided on each tier.

Section 226 provides the scoping requirements for dining surfaces. Once again, 5 percent is the general rule of thumb here. 5 percent of the seating and standing space dining surfaces must be accessible. Please note that this only applies to *fixed* seating and standing spaces.

Section 227.4 addresses food service lines. 50 percent, but no less than one, of each type of self-service shelf must be within accessible reach ranges.

REVIEW QUESTIONS

1. Are lawn seats required to be connected to an accessible route?

A. Yes

B. No

C. Only if there is no other type of seating than lawn seating

D. Only if the wheelchair spaces are designed within the lawn seating area

2. If there are 10 women's dressing rooms within the same area of the building, how many must be accessible?

A. 1

B. 2

C. 3

D. 4

3. If a new restaurant has four (4) dining areas that each offer a different type of dining experience, how many must have an accessible route to them?

A. 5%

B. 25%

C. 50%

D. 100%

Technical Requirements

Accessible Seats

Now that we know what needs to be accessible within assembly areas, it is helpful to understand the requirements for making those elements accessible. Accessible seats in assembly areas must be located on level ground that is stable, firm, and slip-resistant with a slope no greater than 1:48. There is an exception for those seats located in the areas of sports activities. (*802.1.1; 302*) The width of a single wheelchair space is 36 inches minimum. If two wheelchair spaces are designed to be directly next to each other, that width may go down to 33 inches. (*802.1.2*) The depth of the wheelchair space depends on how you enter it. If it can be entered from the rear, the space needs to be at least 48 inches deep. If you can only access it from the side, it must be at least 60 inches deep. (*802.1.3*)

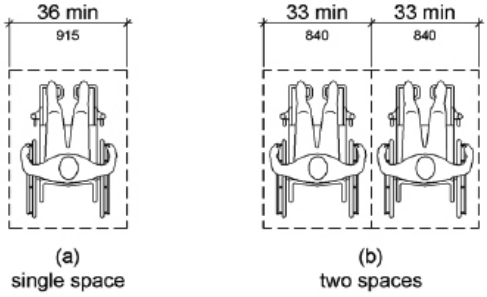


Figure 802.1.2 Width of Wheelchair Spaces in Assembly Areas

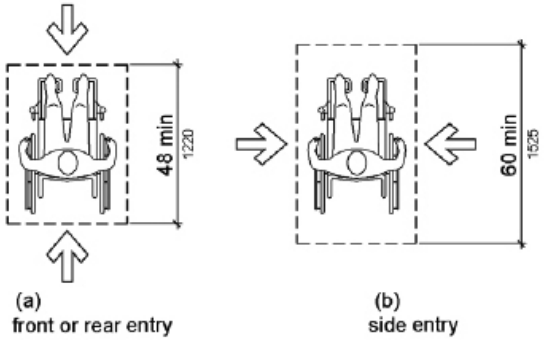


Figure 802.1.3 Depth of in Assembly AreasWheelchair Spaces

In case it is not obvious, the *ADA Standards* require wheelchair spaces to be on an accessible route. Neither the accessible route nor the required circulation paths may overlap the wheelchair spaces. Access to one wheelchair space cannot be through another wheelchair space.

The ADA Standards also address visual access to the screen, performance area, or playing field for spectators sitting in designated wheelchair spaces. Wheelchair users must be afforded similar views as non-wheelchair users. If the standard seats were designed so that seated spectators can see over the heads of those sitting directly in the row in front of them, the wheelchair spaces must be designed the same way. (*802.2.1.1*) If the standard seats were designed so that seated spectators must look between the heads of the seated spectators

directly in front of them, it is acceptable for the wheelchair users to do the same. (*802.2.1.2*) The same concept is true for events with standing spectators. The wheelchair users must be afforded similar views as the standing spectators. This would require that the wheelchair spaces with rows in front of them be at a higher elevation for standing spectators than for seated spectators. If a venue is designed for both types of events, it should be designed for standing spectators.

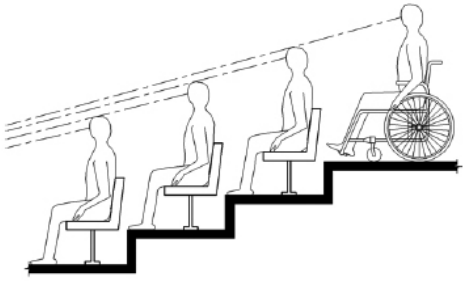


Figure 802.2.1.1 Lines of Sight Over the Heads of Seated Spectators

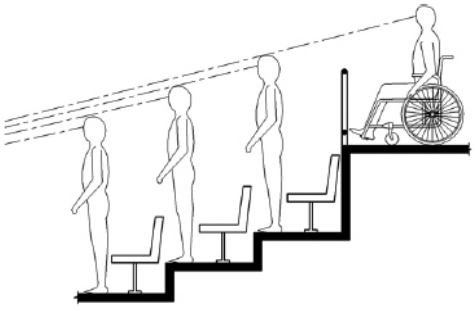


Figure 802.2.2.1 Lines of Sight Over the Heads of Standing Spectators

Companion Seats

As mentioned in the scoping section, each wheelchair space must have a companion seat. (*221.3*) The specific requirements for companion seats may be found in *Section 802.3*. Companion seats must be directly next to the wheelchair space so that the shoulders of the two are aligned. The shoulder alignment point is measured 36 inches from the wheelchair space's front edge. Both the wheelchair space and the companion seat must have the same floor elevation. Companion seats must be comparable to the other seats in that general area. They cannot be of different caliber in terms of size, quality, comfort, and amenities.

Designated Aisle Seats

The other type of accessible seat in assembly areas is the designated aisle seat intended for people who have difficulty walking. These are often used by patrons using walkers and canes. An individual in a wheelchair may also choose to transfer to an aisle seat rather than remain in their wheelchair during the event. The only difference between accessible aisle seats and other aisle seats is that accessible aisle seats have folding or retractable armrests and signs identifying them. (*802.4*) They also need to be near an accessible route.



Designated Aisle Seat (Photo by Course Author)

Assistive Listening Systems

There are only a few technical requirements for assistive listening systems in *Section 706*. The receiver jacks must be a 1/8-inch standard mono jack. The hearing-aid compatible receivers must interface with telecoils in hearing aids through the provision of neckloops. A sound pressure level of 110 dB minimum and 118 dB maximum with a dynamic range on the volume controls of 50 dB must be provided with the assistive listening systems. The signal-to-noise ratio (SNR) for internally generated noise in assistive listening systems must be at least 18 dB. The peak clipping cannot exceed 18 dB of clipping relative to the peaks of speech.

The *ADA Standards* includes an informative advisory for this section for those of us who are not well versed in the terminology.

> ***Assistive listening systems are generally categorized by their mode of transmission. There are hard-wired systems and three types of wireless systems: induction loop, infrared, and FM radio transmission. Each has different advantages and disadvantages that can help determine which system is best for a given application. For example, an FM system may be better than an infrared system in some open-air assemblies since infrared signals are less effective in sunlight. On the other hand, an infrared system is typically a better choice than an FM system where confidential transmission is important because it will be contained within a given space.***
>
> ***The technical standards for assistive listening systems describe minimum performance levels for volume, interference, and distortion. Sound pressure levels (SPL), expressed in decibels, measure output sound volume. Signal-to-noise ratio (SNR or S/N), also expressed in decibels, represents the relationship between the loudness of a desired sound (the signal) and the background noise in a space or piece of equipment. The higher the SNR, the more intelligible the signal. The peak clipping level limits the distortion in signal output produced when high-volume sound waves are manipulated to serve assistive listening devices.***
>
> ***Selecting or specifying an effective assistive listening system for a large or complex venue requires assistance from a professional sound engineer. The Access Board has published technical assistance on assistive listening devices and systems.***

Dressing, Fitting, and Locker Rooms

What makes a dressing, fitting, or locker room accessible? It will have a turning space. This would either be a 60-inch diameter circular space or a T-shaped space within a 60-inch square, as shown in *Figure 304.3.2*. (*803.2*) Doors cannot swing into the room unless a 30-inch x 48-inch clear floor space is provided beyond the arc of the door swing. (803.3)

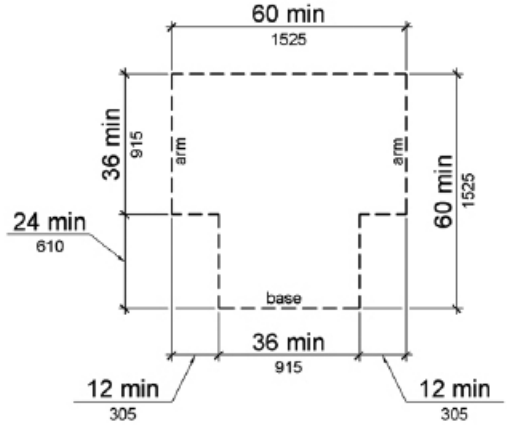


Figure 304.3.2 T-Shaped Turning Space

Something that gets flagged time and time again during accessible plan reviews and inspections is the requirement for accessible benches in

the accessible dressing, fitting, and locker rooms. (*803.4*) For a bench to be accessible, it must have a 30-inch by 48-inch clear floor space at the end of it. It should be parallel to the short side of the bench, so a person in a wheelchair can park beside the bench and transfer onto it. The seat must be between 20 and 24 inches deep, at least forty-two inches long, and 17 to 19 inches above the floor. If the bench is not attached to the wall, a back support at least forty-two inches long is required. It cannot be positioned with more than a 2-inch vertical gap or a 2 ½-inch horizontal gap between the seat and the back support. See Figure 903.4. (*903*)

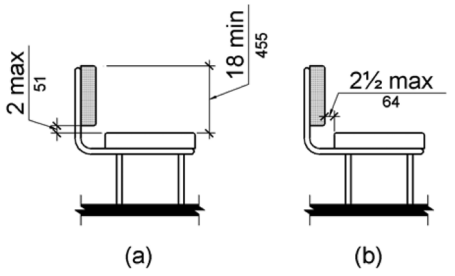


Figure 903.4 Bench Back Support

There is a requirement for accessible coat hooks and shelves in dressing, fitting, or locker rooms, if provided. If there are no individual compartments in the room, at least one of each type must be located within an accessible reach range within the room. (*222.2*, *803.5*) If there is no obstruction in front of the coat hook, the accessible reach range is 15 to 48 inches above the ground. If there are obstructions, the reach depth may not be greater than 25 inches. The reach height can be reduced based on the reach depth. See Figures 308.2.2, 308.3.1, and 308.3.2. Accessible shelves must be installed between 40 and 48 inches above the ground. (*803.5*) If there are individual changing compartments in the room, the accessible coat hooks and shelves must be placed in the compartments that have accessible benches. (*222.2*)

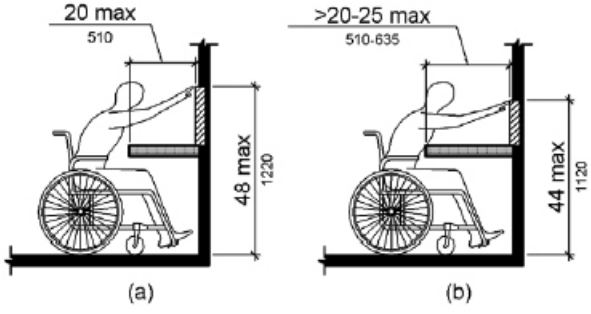


Figure 308.2.2 Obstructed High Forward Reach

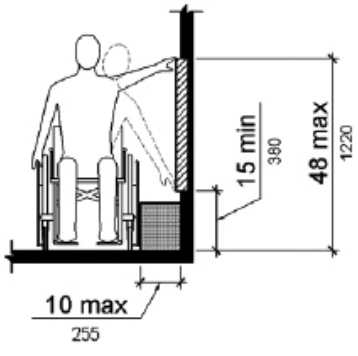


Figure 308.3.1 Unobstructed Side Reach

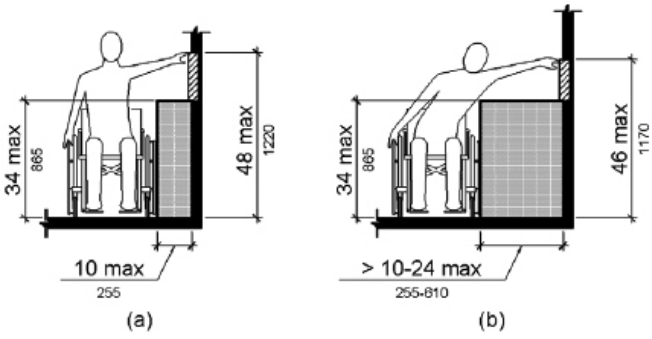
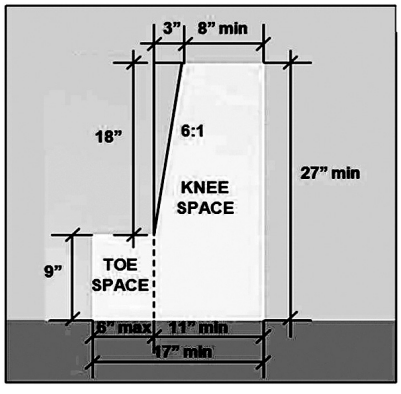


Figure 308.3.2 Obstructed High Side Reach

Restaurants – Dining Surfaces

We learned in the scoping section that 5 percent of dining surfaces must be accessible. To be accessible, it must have a 30-inch x 48-inch clear floor space positioned for a forward approach. (*902.2*) This requires adequate knee and toe clearance under the dining surface. Toe clearance is considered the space under an element from the ground up to 9 inches above the ground that extends a minimum of 17 inches and a maximum of 25 inches under an element. Knee clearance is the space under an element between 9 and 27 inches above the ground that extends a minimum of 17 inches and a maximum of 25 inches under an element. From the leading edge of the dining surface beyond a depth of 8 inches, the 27-inch-high knee clearance can be reduced 18 inches to the 9-inch toe space over a 3-inch span. See the Knee and Toe Clearances figure for clarification.



Knee and Toe Clearances (Access Board's ADA Guide)

In addition to providing adequate knee and toe clearance, the tops of the dining surfaces must be between 28 and 34 inches above the ground. (*902.3*) If the dining surface will primarily be used by children, the height may be reduced to between 26 and 30 inches above the ground. (*902.4.2*)

Restaurants – Food Service Lines

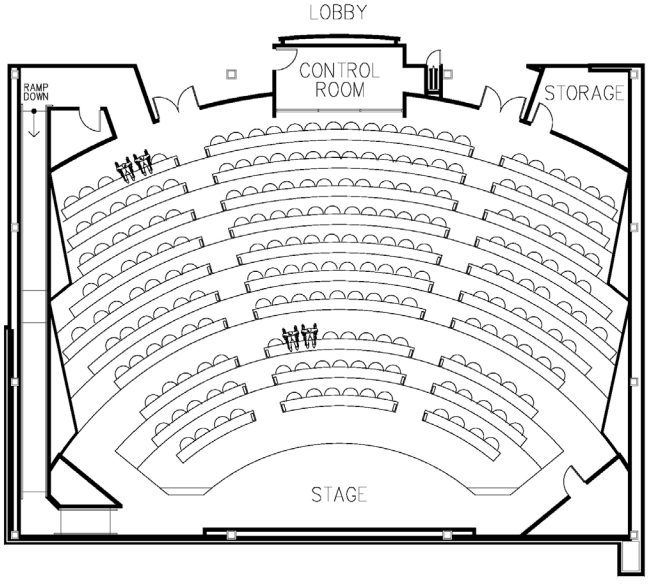
Some restaurants, especially fast-food restaurants, have self-service areas where you may obtain your own tableware and condiments. If so, the self-service shelves and dispensing devices must be within the accessible reach ranges as outlined above. Tray slides have the same height requirements as dining surfaces, between 28 and 34 inches above the ground. (*227.4*)

Case Study

A university student submitted a complaint because he is temporarily confined to a wheelchair after a vehicular accident and does not think that there are enough seating options in his English 101 class. A Facilities Department architect has been tasked with determining whether the room is accessible under the *2010 ADA Standards* or if modifications are required.

First, the architect finds a floor plan of the room to review. (See graphic *University Lecture Hall Plan*.) She notes that there are a total of 216 seats. Four (4) seats are shown as being wheelchair accessible. How many are required? The architect references *Table 221.2.1* in the *ADA Standards* and discovers that five (5) seats are required to be wheelchair accessible if the total number of seats is between 151 and 300. She notes to confirm the number of standard and wheelchair accessible seats in the room.

After skimming through *Sections 221.2.1.2, 221.2.1.3*, and *221.2.1.4*, the architect determines that they do not apply because the room is in a classroom building, not a sports venue. *Section 221.2.2* identifies the seating integration requirements for the accessible seats; they must be an integral part of the seating plan. On the plan, she found that it appears to be the case, so there should not be any issues there.



University Lecture Hall Plan

The highlights noted from the next sections in the *ADA Standards (221.2.3, 221.2.3.1,* and *221.2.3.2)* include:

1. Wheelchair spaces must be dispersed and provide seating options that are equivalent to the seats other students have.
2. Horizontal dispersion is required of the wheelchair seats unless there are 300 or fewer seats, AND the wheelchair/companion seats are located in the 2nd or 3rd quartile of the total row length.
3. Vertical dispersion is required for the wheelchair spaces unless there are 300 or fewer seats AND the wheelchair spaces provide viewing angles equal to, or better than, the average viewing angle provided.

The architect notes that the wheelchair spaces on the plan are shown to be dispersed vertically. There are fewer than 300 seats, so the dispersion exceptions may apply. After rereading *Section 221.2.3.1*, she determines that the horizontal dispersion exception does not apply because the seats at the back of the lecture hall are NOT within the 2nd and 3rd quartiles of the total row length.

After reading *Section 221.3*, the plan is reviewed for companion seats. Each wheelchair space shown has a companion seat next to it, so the architect will confirm that those seats are there in person, as well.

The architect then walks to the room so she can confirm the actual conditions match the floor plan. (See image *Lecture Hall – View 1*.) Immediately, she notices that two chairs in the back row are mobile. So, those must be the allocated wheelchair seats. The distance between the table at the wheelchair spaces and the parallel rear wall is 5'-4". The table is 1'-6" deep. The horizontal distance at the table for the wheelchairs between the posts is almost 6'-0" wide.



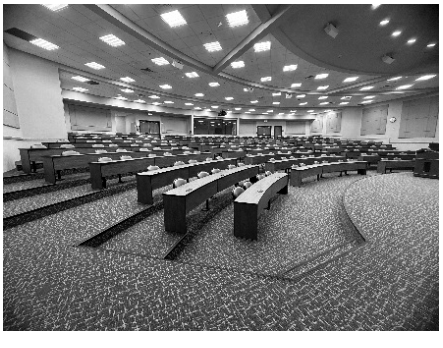
Lecture Hall – View 1

After scribbling the dimensions on the plan, the architect walks around the corner to find the ramp that she spotted. (See image *Ramp – View 2*). It is a carpeted ramp that is 3'-9" wide and has handrails on both sides of it. (*Per Section 405.5*, the clear width of a ramp run and, where handrails are provided, the clear width between handrails shall be 36 inches minimum. Handrails are required on both sides of the ramp according to *Section 505.2*.) The slope appears to be no greater than 1:12, but she plans to put a smart level on it later. (*Section 405.2 requires that* the slope of a ramp run not be steeper than 1:12.) There are multiple 60-inch deep landings on the ramp. (*Section 405.6* allows a maximum rise of 30 inches for any ramp run.)

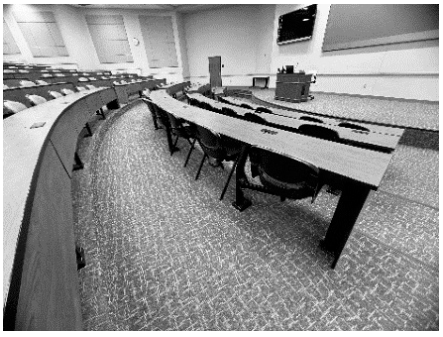


Ramp – View 2

The ramp exits to a level area where you can either go straight to continue to the stage/teaching platform, or you can turn left to go to the seating. (See image *Ramp, Bottom Landing – View 3*). From that vantage point, she sees no additional wheelchair seats. So, she proceeds to walk up the row of seating that is at the same level as the ramp landing. As shown on the plan, there are two (2) mobile seats in the third row in the middle section that indicate the wheelchair seats. There are fixed companion seats on either side of the two wheelchair seats. The cross-aisle leading to the wheelchair seats is 4'-2" wide. The space between the table legs where the wheelchair spaces are located is 5'-6" wide. The tables are 18" deep. (See image *Accessible Seating – View 4*).



Ramp, Bottom Landing – View 3



Accessible Seating – View 4

The architect finishes walking the cross aisle to try to spot another accessible seat, but does not find one. She climbs the stairs on the opposite side from which she came into the room to the top row and does not find any additional accessible seats. So, she goes back to her office to compare her notes with the *ADA Standards*. Since she did not refresh her memory of the technical requirements before going to the classroom, she decided to start there in *Chapter 8*. First, she confirms that the wheelchair spaces meet the 33-inch width requirement. All of the wheelchair spaces may be entered from behind, so they only need to be 48 inches deep. *Section 802.1.4* causes concern because it states that the wheelchair spaces must be on an accessible route, and the accessible route cannot overlap the wheelchair spaces. At first, it appears that you would have to go through one wheelchair space on the third row to get to the adjacent wheelchair space. However, there is another accessible route through the stage area.

Section 802.1.5 does not allow wheelchair spaces to overlap circulation paths. The advisory associated with this section notes that the circulation paths are the aisle widths required by applicable building or life safety codes. All wheelchair spaces are off of aisle accessways and not aisles. If the section was applicable to aisle accessways, there is still adequate width. Twelve (12) inches is required per the *2021 International Building Code*, *Section 1030.13.1.1.*

The architect's recommendation was to remove the fixed seat on the other end of the middle section of the third row to create the required fifth wheelchair seat. This would improve the horizontal dispersion, and it resulted in satisfying the student. He admitted that he was left-handed, and having a seat at the end of the row was more comfortable for him.

CONCLUSION

There are many considerations for designing accessible assembly occupancies. Accessible wheelchair spaces are a primary concern. Some of the factors that go into the design of accessible wheelchair spaces include seating capacity, type of venue, lines of sight, and ability to provide companion seats. Designated aisle seats assist those who have difficulty walking. Assistive listening systems aid the hard-of-hearing. Auxiliary areas, such as dressing rooms, are not exempt from providing accessibility, as turning spaces and benches are required. Restaurants may have additional requirements to providing wheelchair spaces if there are self-serve areas and food service lines. After taking this course, we hope you have a better idea of what must be accessible in assembly occupancies and how to make it accessible.

REVIEW QUESTIONS

4. What is included in the requirements for a designated aisle seat?

A. It has folding or retractable armrests

B. It has a sign identifying it

C. It is wider than a standard seat

D. Both A and B

5. In the case study presented, how many wheelchair spaces were provided, and how many are required?

A. 4 wheelchair spaces were provided, and 4 are required.

B. 5 wheelchair spaces were provided, and 5 are required.

C. 5 wheelchair spaces were provided, and 5 are required.

D. 5 wheelchair spaces were provided, and 6 are required.

ANSWERS TO REVIEW QUESTIONS

1. Are lawn seats required to be connected to an accessible route?

A. Yes; Correct. Section 221.5 states that any lawn seats and exterior overflow seating areas without fixed seating must be connected to an accessible route.

B. No; Incorrect.

C. Only if there is no other type of seating than lawn seating; Incorrect.

D. Only if the wheelchair spaces are designed within the lawn seating area; Incorrect.

2. If there are 10 women's dressing rooms within the same area of the building, how many must be accessible?

A. 1; Correct. Section 222 requires that 5 percent be accessible. 10 x .05 = .5. So, 1 is required.

B. 2; Incorrect.

C. 3; Incorrect.

D. 4; Incorrect.

3. If a new restaurant has four (4) dining areas that each offer a different type of dining experience, how many must have an accessible route to them?

A. 5%; Incorrect.

B. 25%; Incorrect.

C. 50%; Incorrect.

D. 100%; Correct. Section 206.2.5 requires that an accessible route be provided to all dining areas. The exceptions do not apply because each dining area offers a different type of dining experience.

4. What is included in the requirements for a designated aisle seat?

A. It has folding or retractable armrests; Incorrect.

B. It has a sign identifying it; Incorrect.

C. It is wider than a standard seat; Incorrect.

D. Both a and b; Correct. Section 206.2.5 requires that an accessible route be provided to all dining areas. The exceptions do not apply because each dining area offers a different type of dining experience.

5. In the case study presented, how many wheelchair spaces were provided, and how many are required?

A. 4 wheelchair spaces were provided, and 4 are required; Incorrect.

B. 4 wheelchair spaces were provided, and 5 are required; Correct. There were 4 wheelchair spaces in the room. Table 221.2.1 requires 5 wheelchair spaces if the seating capacity is between 151 and 300.

C. 5 wheelchair spaces were provided, and 5 are require; Incorrect.

D. 5 wheelchair spaces were provided, and 6 are required; Incorrect.

Notes

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SEISMIC DESIGN BASICS FOR ARCHITECTS

DESIGNING BUILDINGS FOR EARTHQUAKES

Course #: AlAPDH278
3 LU | HSW Hours

FINAL EXAM

1. **Earthquake resistant design is also referred to as?**
   A. Tectonic design
   B. Seismic design
   C. Resilient design
   D. None of the above

2. **"A table holding up a lamp" is an example of what type of force?**
   A. Normal Force
   B. Gravitational Force
   C. Applied Force
   D. Electrostatic Force

3. **What kind of force causes earthquakes?**
   A. Centripetal force
   B. Gravitational force
   C. Lateral force
   D. Electromagnetic force

4. **Which of the following are classifications of earthquakes by origin?**
   A. Tectonic
   B. Volcanic
   C. Explosion
   D. All of the above

5. **Energy released by earthquakes travels in which of the following types of "Body" waves?**
   A. P, S
   B. W, R, P
   C. Both a & b
   D. None of the above

6. **The Richter scale measures what characteristic of an earthquake?**
   A. Magnitude
   B. Intensity
   C. Location
   D. Relative strength

7. **Which of the following are considered collateral hazards of an earthquake?**
   A. Landslides
   B. Tsunamis
   C. Fires
   D. All of the above

8. **Which earthquake resulted in the passage of the Field and Riley Acts in California?**
   A. 1923 Kanto earthquake
   B. 1908 San Francisco earthquake
   C. 1933 Long Beach earthquake
   D. 1978 Palm Springs earthquake

9. **Which agency is considered the foremost global body representing national earthquake engineering societies?**
   A. UNESCO Global Seismic Code and Guidelines Platform
   B. International Association for Earthquake Engineering (IAEE)
   C. Global Seismographic Network (GSN)
   D. International Seismological Centre (ISC)

10. **Which of the following are partners within NEHRP?**
    A. USGS
    B. FEMA
    C. NIST
    D. All of the above

11. **An example of a building in IBC Risk Category III would be:**
    A. Fire Station
    B. A luxury residence
    C. Hospital
    D. Agricultural storage structure

12. **The structure widely cited as the oldest surviving earthquake resistant building is:**
    A. Taj Mahal
    B. The Wall of Constantine
    C. Machu Pichu, Peru
    D. Tomb of Cyrus the Great, Iran

13. **In Seismic Design, who is considered the "captain of the team"?**
    A. Structural Engineer
    B. Architect
    C. Geotechnical Engineer
    D. Seismic / Structural Peer Reviewer

14. In which phase of design does an architect coordinate structural grids, shear wall placements and diaphragm layout for seismic design?

A. Construction Documents

B. Design Development

C. Schematic Design

D. These are structural engineering responsibilities, and the architect does not engage

15. In the United States, which state requires a supplemental exam focused on seismic design to grant an architectural license?

A. Nevada

B. New York

C. Idaho

D. California

16. Structural solutions for seismic design include which of the following?

A. Moment-Resistant Frames

B. Diaphragms

C. Braced Frames

D. All of the above

17. What is "Isostatic" design?

A. A foundation designed to absorb strong dead loads

B. Use of cantilevered, irregular floors

C. A specialized, low-strength truss system that extends from the ground up to the top floor

D. A technique that inherently provides superior performance against lateral loading conditions

18. The Taipei 101 building is famous for which seismic design element?

A. X-Bracing

B. Tuned Mass Damper

C. Mat foundation

D. Very tall mast at the top of the building

19. One of the objectives of computational modelling and developing digital twins is?

A. To reduce embodied carbon of the life of the building

B. Eliminate the need for building codes

C. Simulate structural response under multiple earthquake scenarios

D. Replace the need for engineers in the design process

20. ASCE 7 will likely continue to move _____ Performance-Based, _____ design.

A. In synch with, integrated

B. Away from, prescriptive

C. Toward, Risk-targeted

D. Into, Flexible

SEISMIC (EARTHQUAKE) DESIGN BASICS
DESIGNING BUILDINGS FOR EARTHQUAKES

By: Muhammad A. Siddiqui, RA, NCARB.

Course Summary

When architects and engineers build structures, a fundamental aspect of designing the building is to enable it to withstand the many forces acting upon it and stand firm and stable. Regardless of where a building or structure is located, it must respond to the natural forces it encounters. These can range from the always present hydrostatic pressures on foundations and wind loads on the superstructure to more extreme and geography specific forces like Seismic, ice and thermal loads. This course will focus on Seismic (earthquake) forces and how buildings are designed to withstand the challenges posed by these forces.

The course is structured into four parts as noted below:

PART 1: BACKGROUND – The Nature of Seismic Forces

PART 2: REGULATIONS – The Codes and Categories Guiding Seismic Design for Public Safety

PART 3: SOLUTIONS – The Architectural and Engineering Responses to Mitigate Seismic Challenges

PART 4: FUTURE – Looking Beyond Surviving Earthquakes to Resilience and Active Adaptability

Learning Objectives

There are five main learning objectives of the course:

1. Understand the nature of dynamic Lateral forces and Seismic forces in particular.
2. Become familiar with how Seismic forces impact structures and the fundamental engineering used to provide stability and resilience in response to earthquakes.
3. Familiarization with the primary codes and regulations governing seismic design in the United States, including Seismic Design Categories, Seismic Zone Maps and key state specific requirements and broader Nationwide requirements.
4. Understand the complimentary roles of the Architect and Structural Engineer in addressing Seismic design solutions.
5. Examine how seismic design is evolving with the use of Smart structures, A.I., and new techniques that move beyond just preventing collapse to creating adaptive, resilient buildings that can regain rapid functionality following a design-level seismic event.

PART 1 – BACKGROUND: THE NATURE OF SEISMIC FORCES

1.1. INTRODUCTION

The Earth and everything on it are always in a state of motion. Some of the movements are obvious, others more subtle but still perceptible to human senses, yet others are seemingly static, even though at a molecular level nothing is ever completely stationary, not even things that are inanimate. What makes everything dynamic are the various types of forces in play throughout the universe. These forces of motion are pushes or pulls that change an object's movement. Based on current levels of understanding, these are categorized mainly as Contact Forces, Non-Contact Forces, Fundamental Forces and Specialty Forces.

- **CONTACT FORCES** [1]

These types of forces result from physical contact between two objects. Examples are:

- Frictional Force: Opposes the relative motion between two surfaces in contact (e.g., brakes slowing a car).
- Normal Force: The upward support force exerted by a surface (e.g., a table holding up a lamp).
- Applied Force: A force directly applied to an object by a person or another object (e.g., pushing a door).
- Tension Force: Transmitted through a string, rope, or cable when it is pulled tight by forces acting from opposite ends.
- Spring (Elastic) Force: The force exerted by a compressed or stretched spring upon any object that is attached to it.
- Air Resistance (Drag): A type of friction that acts on objects as they travel through the air.

- **NON-CONTACT FORCES** [2]

Also known as "Action-at-a-Distance" forces, these act even when two objects are not in physical contact. Examples are:

- Gravitational Force: The attraction between any two objects with mass (e.g., the Earth pulling objects toward its center).
- Magnetic Force: Attraction or repulsion between magnetic poles.
- Electrostatic Force: Attraction or repulsion between two charged particles

- **FUNDAMENTAL FORCES** [3]

At the most basic level, scientists recognize four fundamental interactions that govern everything in the universe:

- Gravitational Force: Responsible for planetary orbits and keeping objects on the ground.
- Electromagnetic Force: Responsible for electricity, magnetism, and the structure of atoms.
- Strong Nuclear Force: The strongest force, which binds protons and neutrons together in an atom's nucleus.
- Weak Nuclear Force: Involved in certain types of radioactive decay and nuclear fusion.

- **SPECIALTY FORCES** [4]

Sometimes also called "Derived Forces", these are specific manifestations or combinations of forces often used in engineering and daily life applications. Examples are:

- Buoyant Force (Upthrust): An upward force exerted by a fluid on an immersed object.
- Lift Force: An upward force that opposes weight, typically generated by wings moving through air.
- Centripetal Force: A center-seeking force that keeps an object moving in a curved path.
- Thrust: A force that moves an object forward, such as that produced by an engine.
- Van der Waals Force: Weak intermolecular forces that occur between neutral molecules.

Several of the above forces and many combinations of them act on buildings or structures in a variety of ways that can cause the structure to destabilize, in whole or in part. Of course, the intensity and direction of the force or forces play a significant role in how a structure is affected. Understanding the likely forces and their potential impacts on a structure is crucial to determining how to address, mitigate and, preferably, neutralize the impacts so that the structure remains stable and the motions have minimal to no perceptible effect on the users.

1 Physicsclassroom.
2 Ibid
3 www.science.nasa.gov: The Four Fundamental Forces
4 www.google.com

Since the scope of this course is on design for earthquakes (seismic design conditions), the most relevant set of forces are a special subset of forces known as "Lateral Forces". These are generally Contact Forces (physical interaction of the structure with motion on the ground) or an applied force such as tectonic displacement). Lateral forces can sometimes be classified as non-contact such as wind loads (considered a microscopic contact force and categorized separately from mechanical contact forces). The term "lateral" typically describes the direction of a force (horizontal or sideways relative to an axis), the force is generally classified as a contact force, but that can depend on the context of the physical interaction.

For this course, the main forces of interest are those that directly lead to earthquakes. Lateral forces cause earthquakes when immense tectonic plate movements create horizontal stress (shear stress) along faults in the Earth's crust. As plates slide, collide, or pull apart, friction locks them in place, causing deformation and energy buildup until the rock breaks, releasing energy as seismic waves.[5]

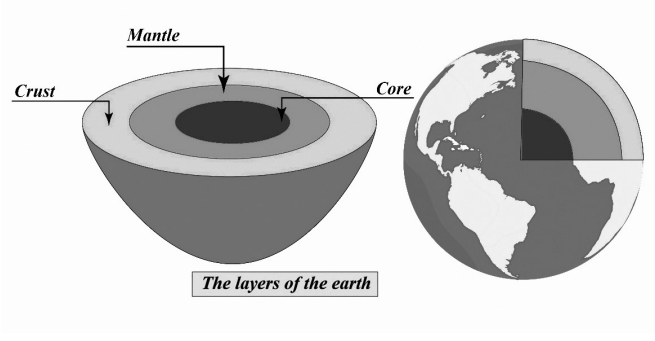
The next section will go into a deeper exploration of the way earthquakes develop and the seismic forces that create discernable ground movement.

1.2. SEISMIC FORCES – THOSE THAT CAUSE EARTHQUAKES

The word seismic will be used extensively in the course, often synonymously with earthquakes. "Seismic" literally means "relating to earthquakes or other vibrations of the earth and its crust".[6] A seismic force is the lateral, inertial or vertical force exerted on a structure due to ground acceleration during an earthquake. Unlike gravity loads, these dynamic forces are generated internally by the structure's mass trying to resist movement. This typically causes horizontal shaking, or "base shear".

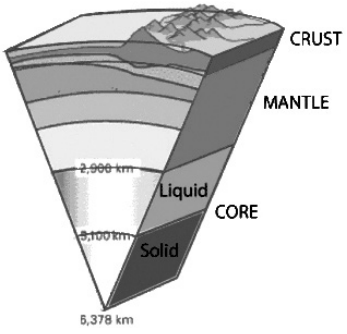
To better understand how seismic forces and earthquakes develop, it is worthwhile to understand basic earth geology and plate-tectonics.

In the most basic terms, the Earth is made up of three layers as illustrated below:



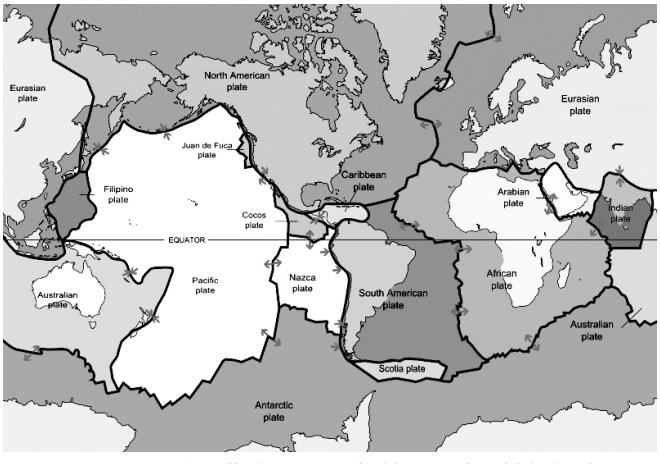
Source: Wikimedia Commons: Rajneesh Kumar Thakur; "The layers of the Earth model.jpg".

Within these layers, the core has a liquid and solid part as illustrated below:



Source: USGS.gov /Public Domain
A simplified diagram of the crust (brown), mantle (orange), and core (liquid in light gray, solid in dark gray) of the earth.

The crust and the top of the mantle make up a thin "skin" on the surface of our planet. This rigid outermost shell is also referred to as the lithosphere. This is the layer humans and most life on earth lives on and where earthquakes are felt. This "skin" is not all in one piece – it is made up of many pieces like a puzzle covering the surface of the earth.7 The Earth's lithosphere is divided into 7 major, 8 secondary, and dozens of minor/micro-plates that constantly move. The seven primary plates—Pacific, North American, Eurasian, African, Antarctic, Indo-Australian, and South American—make up roughly 94% of the Earth's surface.



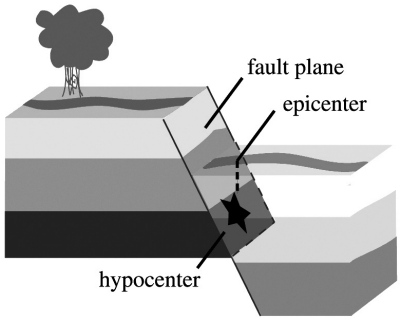
Source: USGS, http://pubs.usgs.gov/publications/text/slabs.html, public domain, via Wikimedia Commons

These pieces or plates keep slowly moving around, sliding past one another and bumping into each other. Geologists call these pieces tectonic plates, and the edges of the plates are called the plate boundaries. The plate boundaries are made up of many faults, and most of the earthquakes around the world occur on these faults. Since the edges of the plates are rough, they get stuck while the rest of the plate keeps moving. Finally, when the plate has moved far enough, the edges unstick on one of the faults and there is an earthquake.[8]

An earthquake happens when two blocks of the earth suddenly slip past one another. The surface where they slip is called the fault or fault plane. The location below the earth's surface where the earthquake starts is called the hypocenter, and the location directly above it on the surface of the earth is called the epicenter.[9]

5 Ibid
6 https://languages.oup.com/google-dictionary-en/
7 USGS.gov: The Science of Earthquakes
8 Ibid
9 Ibid

See illustration below:



Source: USGS.gov /Public Domain

A normal (dip-slip) fault is an inclined fracture where the rock mass above an inclined fault moves down

All earthquakes are not the same and the lateral forces that generate them cause different dynamics on the surface. These dynamics and how to navigate and manage them are what concern architects and engineers.

Earthquakes can be classified by fault movement or by trigger origin.

1. Classification by Fault Movement

The most common way to describe earthquake movement is through the type of fault rupture that occurs:

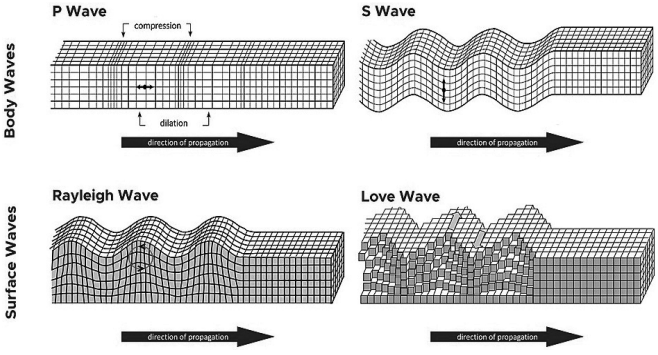
1. **Normal Earthquakes (Tensional)**: These occur when two plates pull apart (divergent boundaries). One block of rock (the hanging wall) slides downward relative to the other (the footwall).
2. **Reverse or Thrust Earthquakes (Compressional)**: These occur when plates push together (convergent boundaries). One block is forced upward and over the other. These are responsible for the world's most powerful "megathrust" quakes.
3. **Strike-Slip Earthquakes (Horizontal):** These occur when plates slide horizontally past one another (transform boundaries). The movement is side-to-side with little to no vertical displacement.
4. **Oblique-Slip Earthquakes:** These involve a combination of both vertical (dip-slip) and horizontal (strike-slip) movement.

2. Categories by Origin

- **Tectonic**: The most common type, caused by the sudden release of energy as tectonic plates slide past, collide, or pull away from each other. 90-95% of all earthquakes are of this type, occurring at plate boundaries.[10]
- **Volcanic**: Triggered by the movement of magma beneath the surface before or during a volcanic eruption.
- **Collapse**: Small earthquakes occur when underground caverns or mines collapse.
- **Explosion**: Caused by the detonation of chemical or nuclear devices

1.3. SEISMIC WAVES AND EARTHQUAKE INTENSITY

As we have seen in the previous section, the dynamics of tectonic movements and other geological phenomenon can create earthquakes. When the earthquakes do occur the energy, they unleash travels in waves that move the ground as "Body Waves" or "Surface Waves". These in turn are made up of a subset of waves as illustrated below:



Source: Wikimedia Commons Overview Seismic Waves

- **P-Waves (Primary):** Compressional waves that push and pull the ground in the same direction the wave travels (like a slinky).
- **S-Waves (Secondary):** Shear waves that move the ground up and down or side to side, perpendicular to the wave's path. These arrive after P-waves and cause more damage.
- **Surface Waves:** These travel along the Earth's surface and create a rolling or swaying motion, often responsible for the most severe structural damage.

Since all earthquakes are not the same, their impact is also variable. This makes it important to be able to measure or scale an earthquake. Measuring earthquake intensity (ground shaking/damage) and magnitude (energy released) is critical for assessing immediate danger, directing emergency response, and improving infrastructure resilience. These measurements allow engineers to design safer, earthquake-resistant structures based on local soil conditions and help officials update building codes to reduce future risks.

- **Intensity:** Measures the effects of an earthquake (what people felt, and damage caused) at a particular location. It is not not a single value; it decreases farther from the epicenter.
- **Severity:** Describes the overall impact or damage level, sometimes synonymously with magnitude (energy released) or high-intensity shaking. This is helpful in determining the emergency response.

A single earthquake typically has one value for magnitude but may have multiple intensity values.

The above are measured differently. Intensity is rated by Roman numerals (e.g., MMI), while the overall size of an earthquake is measured by magnitude (e.g., Richter or Moment Magnitude scale). The description and illustrations below explain these scales:

The Modified Mercalli Intensity (MMI) scale: Measures the intensity of an earthquake at a given location. Intensity estimates are important because they allow us to characterize parts of any region into areas that are especially prone to strong shaking versus those that are not. The key factor in this regard is the nature of the underlying geological materials, and the weaker those are the more likely it is that there will be strong shaking. Areas underlain by strong solid bedrock tend to experience much less shaking than those underlain by unconsolidated river or lake sediments.[11]

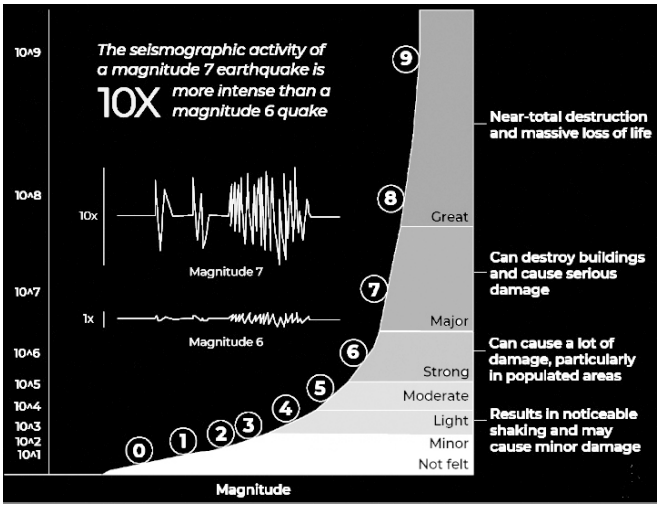
10 Google AI

11 Thompson Rivers University: ENVIRONMENTAL GEOLOGY; 6.3 measuring Earthquakes

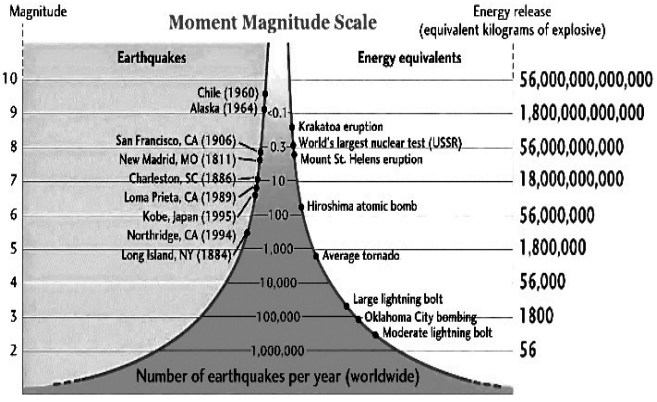
I	NOT FELT	Not felt except by a very few under especially favorable conditions.
II	WEAK	Felt only by a few persons at rest, especially on upper floors of buildings.
III	WEAK	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to that of a passing truck. Duration estimated.
IV	LIGHT	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	MODERATE	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	STRONG	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	VERY STRONG	Damage negligible in buildings of good design and construction; considerable damage in poorly or badly designed structures; some chimneys broken.
VIII	SEVERE	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	VIOLENT	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	EXTREME	Some well-built structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.
XI	EXTREME	Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

The Modified Mercalli Intensity Scale [12]

For measuring earthquake magnitude, the scale most people are familiar with is the Richter scale (ML). However, there is another, arguably more effective method called the Moment Magnitude Scale (MMS or Mw). Both are logarithmic scales (meaning each whole number increase represents a 10-fold increase in measured wave amplitude). Richter is an older, amplitude-based method suitable for small-to-medium earthquakes. The Moment Magnitude Scale is the modern, preferred standard for accurately calculating the total energy of large, distant earthquakes. The Richter scale "saturates" for large earthquakes, meaning it underestimates their size. The Moment Magnitude Scale is more reliable for massive earthquakes (i.e.., Magnitude 7.0 or higher) [13]



Richter Scale *Source: United States Geological Survey.*



Source: Geology n; "Moment Magnitude Scale: Definition, Importance, Uses"

Even though the Moment Magnitude Scale is preferred in the scientific community, The Richter scale remains the most popular in public discourse, partly because of its relative simplicity, familiarity and apparent scale of 10. It should be noted that neither of these scales has an upper limit since they are logarithmic but 10 is generally considered the theoretical limit for tectonic earthquakes. The largest earthquake recoded by instruments has been the 1960 Chilean Earthquake – the Valdivia Earthquake with a magnitude of 9.5 on the Moment magnitude Scale.

To measure the effect of an earthquake on the ground (ground motion), the following definitions are commonly used:[14]

- ***Acceleration*** is the rate of change of speed, measured in *"g"s at 980 cm/sec² or 1.00 g.*

  For example,
  - *0.001g or 1 cm/sec² is perceptible by people*
  - *0.02 g or 20 cm/sec² causes people to lose their balance.*
  - *0.50g is very high but buildings can survive it if the duration is short and if the mass and configuration have enough damping*
- ***Velocity*** (or speed) is the rate of change of position, measured in centimeters per second.
- ***Displacement*** is the distance from the point of rest, measured in centimeters.
- ***Duration*** is the length of time the shock cycles persists.
- ***Magnitude*** is the «size» of the earthquake, measured by the Richter scale, which ranges from 1-10. The Richter scale is based on the maximum amplitude of certain seismic waves, and seismologists estimate that each unit of the Richter scale is a 31 times increase of energy. *Moment Magnitude Scale* is a recent measure that is becoming more frequently used as noted above.

If the level of acceleration is combined with duration, the power of destruction is defined. Usually, the longer the duration, the less acceleration the building can endure. A building can withstand very high acceleration for a very short duration in proportion with damping measures incorporated in the structure.

Intensity is the amount of damage the earthquake causes locally, which can be characterized by the 12 level *Modified Mercalli Scale* (MM) where each level designates a certain amount of destruction correlated to ground acceleration. Earthquake damage will vary depending on distance from origin (or epicenter), local soil conditions, and the type of construction.

12 Ibid
13 Wikipedia; 2006
14 WBDG.org: Whole Building Design Guide; "Seismic Design Pribciples"

1.4. HOW EARTHQUAKES CAUSE DAMAGE TO BUILDINGS AND STRUCTURES

Given the nature of the forces that create earthquakes, it is clear that depending on the intensity and magnitude, these can cause severe disruption to the stability of the earth's surface where most buildings and structures are built and people live. The violent shaking of the ground leads to the destructive effects of earthquakes. The ground shaking is what triggers the vicious cycle of ruptures in the earth, which can result in landslides, tsunamis, tidal waves, liquefaction and fires. All these together, or individually, can lead to damage of personal property, infrastructure, and loss of lives.[15]

The magnitude of the earthquake is a factor in its destructive power but another, even more relevant factor for structures is the depth of the earthquake. Even if two earthquakes have the same magnitude, their depths can make a big difference in how much damage they cause and how strongly they are felt on the surface. Shallower quakes tend to be much more destructive because their energy has less distance to travel before reaching people and buildings. [16]

In deeper earthquakes, much of the energy dissipates as it moves through layers of rock. By contrast, shallow ones release their energy closer to the ground, producing stronger shaking and greater damage in populated areas.[17]

There are typically three measurements used to classify earthquake depth: shallow focus (0-70 km or 0-43 miles), intermediate focus (70-300 km or 43-186 miles), and deep focus (300-700 km or 186-435 miles).[18]

The degree to which earthquakes cause damage to buildings is influenced by the following primary factors:

Earthquake Characteristics:

- Magnitude and Depth: Higher magnitude and shallower earthquakes generally cause more intense, destructive shaking.
- Distance to Epicenter: Proximity to the fault determines the intensity of ground motion, with closer structures sustaining more damage.
- Duration and Frequency: Longer duration and specific frequencies of shaking can cause greater structural damage.

Site and Geological Conditions:

- Soil Type: Loose, water-saturated, or soft soils (e.g., clay) can amplify seismic waves and trigger liquefaction, increasing damage compared to solid rock.
- Topography: Hills or steep slopes can amplify ground shaking.

Building Characteristics:

- Design and Materials: Unreinforced masonry (URM) and rigid, non-ductile concrete buildings are highly vulnerable to collapse. Steel frames and wood-frame structures often offer better flexibility and resilience.
- Structural Configuration: Irregular shapes, tall buildings with flexible lower levels, and lack of reinforcement in joints increase risk.
- Age: Older buildings, built before modern seismic codes, are more susceptible to damage.
- Foundation: A solid foundation can mitigate damage, while weak foundations fail during violent shaking.

Secondary Effects:

- Pounding: Adjacent buildings colliding with each other.
- Collateral Hazards: Landslides, fires, and tsunamis initiated by the earthquake.

Below are some pictures showing the devastation that can result from earthquakes. The pictures are representative of various forms of damage incurred in a variety of places in the world and from quakes of varying intensity.



Muzaffarabad, Pakistan, 2005
Source: Wikimedia Commons; Gregory Takats / AusAID



Seward, Alaska after the Good Friday Earthquake of 1964.
Source: Wikimedia Commons; Public Domain



Earthquake damage in San Francisco's Marina District on the north side of the city from the Loma Prieta Earthquake October 17, 1989.
Source: Wikimedia Commons; Nancy Wong

15 CRMP.org: "How earthquakes cause Damage and Destruction
16 aljazeera.com/news/2025/9/1/why-do-shallow-earthquakes-cause-more-destruction-than-deep-ones; by Marium Ali
17 Ibid
18 Ibid



Fukui Earthquake 1948 - damaged building.
Source: Wikimedia Commons; Bert Cohen; Public Domain



2023 Turkey Earthquake Damage Diyarbakir
Source: Wikimedia Commons; VOA; Public Domain



Earthquake Damage – Roads Christchurch, NZ
Source: Wikimedia Commons; Martin Luff; Public Domain



Semi-collapsed building – 2024 Hualien earthquake, China.
Source: Wikimedia Commons; Shufu Liu; Creative Commons

It is estimated that there are 500,000 detectable earthquakes in the world each year. 100,000 of those can be felt, and 100 of them cause damage.[19] The damage that comes in the aftermath of an earthquake is magnified in areas of concentrated human habitation. Damage – physical, financial and psychological – increases in direct proportion to the population density of the area. As urbanization increases and our knowledge of seismic forces increases, it becomes imperative that regulations and design guidelines be put in place and practiced to mitigate the worst outcomes of an earthquake event.

This section has primarily focused on providing an introductory understanding of the forces that create earthquakes and the impacts of these. The next section will look at how we start the process of mitigation by examining the codes and regulations that have already been developed and those that may be evolving for future implementation.

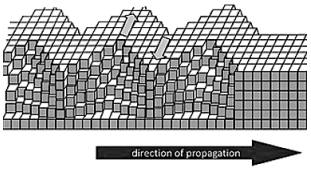
END of PART 1

PART 1 REVIEW QUESTIONS

1. **Which layer of the earth is the portion where earthquakes are felt?**
   A. Mantle
   B. Core
   C. Lithosphere
   D. Stratosphere

2. **The location below the earth's surface where the earthquake starts is called the _____.**
   A. Fault plane
   B. Hypocenter
   C. Epicenter
   D. Crust

3. **This illustration depicts what kind of seismic wave?**



   A. W wave
   B. S wave
   C. Love wave
   D. Rayleigh wave

4. **An earthquake of intensity "V" on the MMI scale would be classified as:**
   A. Violent
   B. Weak
   C. Severe
   D. Moderate

19 USGS.gov: Cool Earthquake Facts

5. **Which of the following building characteristics are better for seismic design?**
   A. Flexible steel frames
   B. Unreinforced masonry
   C. Irregular shape
   D. All of the above

PART 2 – REGULATIONS: GUIDING SEISMIC DESIGN FOR PUBLIC SAFETY

Awareness of earthquakes has existed for a long time, and builders have developed many techniques to enable seismic-resistant buildings. Most of these have been experience and observation based, not due to any formal codes, regulations or design guidelines.

The early seismic regulations emerged in the early years of the 20th century. Among the first were those developed in Italy in 1909. These were based on the performance of wood-framed buildings that experienced the earthquake of 1908. A commission ruled that buildings be designed to resist a lateral force of 1/12 (0.083) of their self-weight. [20]

In the United States, it was not until 1906 when, following the San Francisco earthquake which, combined with the resulting fires, destroyed most of the city, consideration for lateral forces was introduced requiring a wind load of 30 lb./sq ft. While the intent may have been to address wind and seismic, no consideration was given to earthquake forces. However, this did prompt, albeit non-mandatory, research into addressing seismic design.

The first national seismic design code was adopted in Japan in 1924 following the 1923 Kanto earthquake in Japan, which destroyed large parts of Tokyo and Yokohama. This law required that a design seismic coefficient of 0.1g or more should be used for all important new structures.[21]

2.1. DEVELOPMENT OF SEISMIC CODES IN THE UNITED STATES

It was not until 1927 that the first appearance of seismic provisions appeared in the Uniform Building Code (UBC) enacted by the International Conference of Building Officials (ICBO). The seismic provisions were not mandatory and only featured in an appendix, but awareness and concern had been noted. In 1933 the Long Beach earthquake and its consequent damage to public buildings resulted in the passage of the Field Act and Riley Act in California.

- The Riley Act mandated that local governments establish building departments and ensuring structures are designed to withstand specific lateral forces (earthquake safety). It was a critical, early seismic safety measure, setting minimum structural standards for buildings across the state. [22]
- The Field Act mandated strict seismic safety standards, plan reviews, and construction inspections for K-14 public schools, enacted following the 1933 Long Beach earthquake. It authorizes the Division of the State Architect (DSA) to approve designs and inspect construction to ensure earthquake resistance.[23]

After these landmark pieces of legislation, the development and adoption of regulations for seismic design gained momentum and by 1943 Lateral forces requirements were introduced into the UBC. The Key details of the 1943 lateral force requirements include:

- Coefficient Formula: The 1943 UBC introduced a lateral force coefficient (*C*) based on the number of stories (N) above the story under consideration.

  Formula: $C = 0.6 / (N+4.5)$

- Application: Each story was designed to resist a lateral shear force calculated as *C* times the dead load above that level.
- Height Limit: The code limited buildings designed under this formula to 13 stories, though this restriction was removed in later editions.

These provisions marked a shift from earlier, purely static, fixed-percentage lateral load calculations (such as the 8% rule in Los Angeles) toward methods accounting for building dynamics.

Below is a timeline of how the building codes have developed in the United States with respect to seismic design: [24]

DATE	SIGNIFICANT MILESTONE
1906	San Francisco Earthquake prompts initial, non-mandatory research and improved building practices
1927	First appearance of seismic provisions in the Uniform Building Code (UBC), featuring a non-mandatory appendix for seismic design.
1933	Long Beach Earthquake triggers the Field Act and Riley Act in California, mandating the first statewide seismic regulations
1959	Lateral force requirements were adopted in the UBC, leading to stricter standards.
1971	Structural Engineers Association of California (SEAOC) releases the "Blue Book," introducing lateral force recommendations that heavily influenced the UBC.
1977	San Fernando Earthquake highlights vulnerabilities in concrete buildings, spurring more rigorous, dynamic, and ductility-focused code changes.
1988	Passage of the National Earthquake Hazards Reduction Act (NEHRP), establishing a federal, coordinated approach to seismic safety.
	UBC adopts significantly updated, stringent seismic design, raising base shear requirements.
1994	Northridge Earthquake reveals severe vulnerabilities in welded steel connections, initiating major revisions to design standards.
2000	The first International Building Code (IBC) is published, consolidating regional codes (BOCA, SBC, UBC) and creating a unified national standard that is updated every three years.
2000 +	Evolution toward Performance-Based Design, focusing on limiting damage to structures rather than just preventing collapse.

20 Onlinelibrary.wiley.com: "Basic Structural Dynamics";
APPENDIX–HISTORICAL DEVELOPMENT OF BUILDING CODE SEISMIC PROVISIONS by James C. Anderson and Farzad Naeim - 2012

21 Ibid

22 Wikipedia

23 Ibid

24 Table developed by Author based on public information, Wikipedia and Google AI

2.2. GOVERNMENTAL AND REGULATORY AGENCIES INFLUENCING SEISMIC DESIGN

Building codes are the direct mechanism requiring architects and engineers to meet specific minimum design standards to address seismic conditions for a project. However, these codes are not developed in a vacuum. Behind the requirements are a host of supporting global organizations and agencies, both governmental and academic, that inform the seismic landscape globally and locally. The collective information provides the context for any seismic response that building designers must respond to. As discussed in Part 1, tectonic earthquakes are most likely to occur at the edges of the tectonic plates, and these are spread all over the globe. The plates do not recognize political boundaries and, therefore, beneficial understanding of tectonic movements and potential earthquakes requires a degree of international cooperation and consistency of regulatory response. To this end, there are several notable international organizations that study, track and provide guidelines on various seismic topics. The major organizations can be grouped in three categories as noted below. *(Note: These are not hard industry standard classifications but just way to help organize by focus)*

1. **Primary Global Organizations with a Design and Engineering Focus**
   - **International Association for Earthquake Engineering (IAEE)**: The foremost global body representing national earthquake engineering societies. It promotes international cooperation through the World Conference on Earthquake Engineering and maintains the influential publication *"Regulations for Seismic Design: A World List"*.
   - **Global Earthquake Model (GEM) Foundation:** A public-private partnership that develops open-source software and data for seismic hazard and risk assessment. It recently launched the Global Seismic Regulations Database to analyze how building codes influence resilience across different regions.
   - **UNESCO Global Seismic Code and Guidelines Platform:** consolidates international data on seismic codes to support disaster risk reduction.
   - **International Code Council (ICC):** While based in the U.S. and largely adopted in the United States, the ICC provides the International Building Code (IBC), which serves as a global model for seismic design requirements in commercial and residential construction. The ICC family of codes is a source for many other national and regional codes worldwide.
   - **European Association for Earthquake Engineering (EAEE):** Focuses on advancing seismic design practices across Europe.
   - **Structural Engineers Association of California (SEAOC):** Develops seismic data and code recommendations, widely used internationally.
2. **Tracking & Data Networks**
   - **Global Seismographic Network (GSN):** A permanent digital network of over 150 stations worldwide. It provides real-time data for earthquake location, tsunami warnings, and nuclear test monitoring in partnership with the USGS and EarthScope.
   - **International Federation of Digital Seismograph Networks (FDSN):** Coordinates the international deployment of broadband seismometers and facilitates open data exchange between global networks.
   - **International Seismological Centre (ISC):** A non-governmental organization that compiles the most definitive summary of world seismicity by collecting and re-analyzing data from global agencies.
3. **Specialized Research, Regulatory & Policy Bodies**
   - **Earthquake Engineering Research Institute (EERI):** A multidisciplinary technical society that conducts post-earthquake reconnaissance through its Learning from Earthquakes program to improve future seismic design.
   - **International Atomic Energy Agency (IAEA):** Establishes specific Safety Standards for Seismic Design for nuclear installations globally.
   - **Pacific Earthquake Engineering Research Center (PEER):** A multi-institution center that develops performance-based earthquake engineering (PBE) technologies and guidelines for tall buildings and infrastructure.
   - Numerous Geophysics Institutions throughout the world. In the United States the main body is the **USGS (United States Geological Survey)**. The USGS is part of the U.S. Department of the Interior. It began in 1879 to study the nation's lands and resources. Today, the USGS mission is to monitor, analyze, and predict Earth's changing systems. Among one of its primary functions is earthquake and volcano notifications.[25]
   - **National Earthquake Hazards Reduction Program (NEHRP) (USA):** Led by agencies like NIST (National; Institute of Standards and Technology), NSF (National Science Foundation), and USGS to enhance seismic resilience through research and guidelines.
   - **Geotechnical Extreme Events Reconnaissance (GEER):** An NSF-sponsored organization documenting earthquake impacts.
   - **Lettis Consultants International (LCI):** Provides specialized seismic hazard analysis for critical infrastructure. LCI is reputed to have performed many Probabilistic Seismic Hazard Analysis (PSHA) studies for high-consequence facilities and are *"recognized throughout the United States and internationally as a leader in seismic hazard analysis for critical and other highconsequence facilities"*.[26] Competitor firms to LCI, offering similar services, include Fugro, AECOM, WSP/Golder, Wood/AMEC, URS/AEI.

As is clear from the above discussion, there are many groups working on examining seismic activity and influence on building designs. In the United States, the following are the primary seismic regulatory and oversight bodies that govern earthquake safety (some are repetitive from the above list, but the focus of this part is on the US rather than a global view):

1. **Building Codes (IBC, ASCE 7)**

Building codes set minimum seismic design requirements for structures to protect life safety. They govern how buildings are designed, constructed, altered, and maintained. [27]

- **Overseen By:**
  - International Code Council (ICC) publishes the International Building Code (IBC). Seismic design is part of Chapter 16; Section 1613. While Chapter 16 dictates the loads, specific material requirements for seismic resistance are also found in Chapter 18 (Soils and Foundations), Chapter 19 (Concrete), and Chapter 21 (Masonry).

25 Adapted from USGS website

26 MS CoPilot

27 Seismic Building Codes - FEMA.gov. https://www.fema.gov/emergency-managers/risk-management/earthquake/seismic-building-codes

- Local and state governments — adopt and enforce the codes.
- ASCE (American Society of Civil Engineers) — publishes ASCE 7, which defines seismic loads used in IBC.

- **Role in seismic safety:**

  These codes are the primary mechanism for reducing earthquake risk in the built environment.

2. NEHRP (National Earthquake Hazards Reduction Program)

A federal program that coordinates national efforts to understand earthquake hazards and reduce risk. It shapes seismic provisions used in building codes. [28]

- **Overseen By:**

  NEHRP is a partnership among four federal agencies:

  - FEMA — implementation, building codes, public safety.
  - NIST — program lead, research coordination
  - USGS — seismic hazard maps and science
  - NSF — academic research funding

- **Role in seismic safety:**

  NEHRP develops the Recommended Seismic Provisions, which form the technical basis for seismic requirements in the IBC. [29]

3. Federal Seismic Safety Regulations (Executive Order 12699 & 49 CFR Part 41)

Federal rules require seismic safety for federally owned, assisted, or regulated buildings. CFR Part 41 implements Executive Order 12699, mandating seismic safety in federal construction.[30]

- **Overseen By:**
  - U.S. Department of Transportation (DOT) — responsible for developing and implementing seismic safety regulations for its mission areas.
  - Other federal agencies implement similar requirements for their own facilities.

- **Role in seismic safety:**

  Ensures federal buildings meet seismic safety standards, often referencing NEHRP provisions.

The table below summarizes the key seismic regulations and the bodies that regulate them:

REGULATION / PROGRAM	*PURPOSE*	*OVERSIGHT BODY*
IBC / ASCE 7	Seismic design requirements for buildings	ICC, ASCE, state/local governments
NEHRP	National coordination of earthquake hazard reduction	FEMA, NIST, USGS, NSF
49 CFR PART 41 / EO 12699	Seismic safety for federal buildings	U.S. DOT + other federal agencies
NEHRP RECOMMENDED SEISMIC PROVISIONS	Technical basis for seismic code updates	FEMA + Building Seismic Safety Council

For building design, perhaps the most important standard is the ASCE 7, which forms the backbone of seismic design for buildings in the United States and is widely used in other parts of the world. ASCE 7, titled *"Minimum Design Loads and Associated Criteria for Buildings and Other Structures,"* is the primary U.S. standard for determining the structural loads (forces) that buildings must withstand. Developed by the American Society of Civil Engineers (ASCE) and the Structural Engineering Institute (SEI), it is legally adopted by codes like the International Building Code (IBC) to ensure safety and structural integrity. It effectively is the seismic chapter in the IBC.

While architects and engineers take their cues for seismic design from the building codes, almost all buildings requiring seismic design in the United States follow a rigorous pipeline of governance that starts with a PSHA (Probabilistic Seismic Hazard Analysis), is filtered through USGS and NEHRP guidelines that feed the ASCE 7, which is incorporated by the IBC, which guides architects and engineers and whose provisions are ultimately enforced at the local level.

PSHA›USGS›NEHRP›ASCE 7›IBC›Architects/Engineers›Local enforcement

2.3. THE TOOLS AND TERMINOLOGY FOR UNDERSTANDING SEISMIC DESIGN.

Since earthquakes are difficult to predict – in terms of when, where or how big, it is helpful if we can narrow down the statistically likely places and circumstances so that designers can take actions to apply appropriate seismic resistance into their projects. Similarly, having a system of classifications for building responses can help balance the financial risk for the degree of protection relative to the risk of the severity and likelihood of an event. Of course, as a means of safeguarding public safety and welfare, building codes provide minimum seismic design criteria. However, it would be grossly burdensome if seismic requirements were imposed universally across the board. Just as it does not make sense to impose hurricane or tornado resistance requirements in areas where such events are unlikely. Similarly, there is no reason to impose seismic design requirements in areas where geology suggests little to no likelihood of a significant event. Conversely, it is essential to know which areas are susceptible to seismic events and the degree of severity so that designers are mandated to account for these. While the codes and regulations are intended to safeguard life and keep structures from collapse, essential public service facilities may be required to be designed to stricter standards, so they not only do not collapse but remain functional through and after the event. In addition, various property owners and businesses may elect to have their buildings designed to varying degrees of "survivability". In this section, we will examine the various tools that help guide how seismic design is applied by location and type. In addition, we will look at some of the classifications and terms used to qualify seismic resistance and integrity of a building or structure.

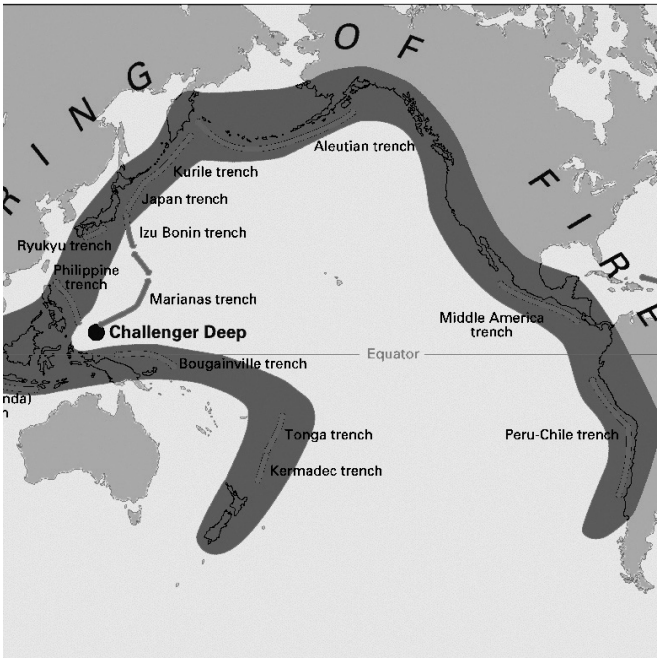
As was noted in Part 1, most earthquakes happen at the edges of tectonic plates. That helps narrow down the most active regions for seismic concern. From among the tectonic boundaries, there is one region that is especially notable. Known as the "Ring of Fire", also called the Circum-Pacific belt, is the zone of earthquakes surrounding the Pacific Ocean — about 90% of the world's earthquakes occur there *(See graphic below)*. The next most seismic region (5-6% of earthquakes) is the Alpide belt (extends from Mediterranean region, eastward through Turkey, Iran, and northern India.[31]

28 NEHRP - National Earthquake Hazards Reduction Program - A research and .... https://www.nehrp.gov/

29 The Role of the NEHRP Recommended Seismic Provisions in the Development .... https://drupal.nibs.org/files/pdfs/FEMA_P-2156_bssc-35-year-ret.pdf

30 eCFR :: 49 CFR Part 41 -- Seismic Safety. https://www.ecfr.gov/current/title-49/subtitle-A/part-41

31 USGS.gov: Cool Earthquake Facts

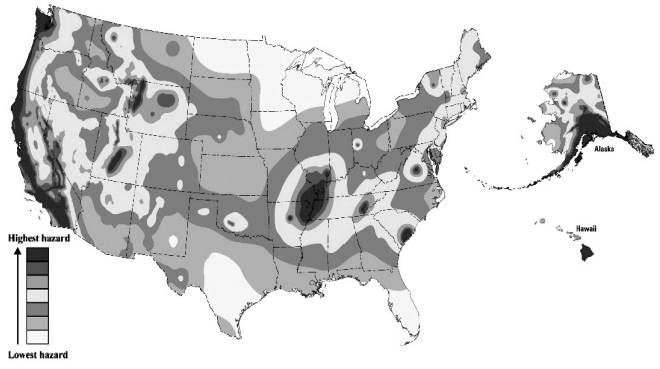


The Ring of Fire

Source: Public Domain; Earthquake Hazards Program; USGS.gov

Even though the "Ring of Fire" accounts for so many earthquakes, it is still a very large are. Along its perimeter, many countries have all developed their own localized zones for seismic activity and levels of intensity.

In the United States, the US Geological Survey (USGS) develops the National Seismic Hazard Maps for the United States, with the latest 2023 model created in collaboration with federal, state, and local partners. These maps, which have been updated periodically since 1996, identify areas prone to significant ground shaking to inform building codes.[32]



Seismic Hazard Map. Source: USGS.gov; Public Domain

An interesting observation from the above map is that, contrary to a comon misunderstaingd, all the seismic areas of concern in the US ar not only along the west coast. There are also significant seismic activity zones in the Mid-west and along the East coast.

Prior to 2000, under the old UBC, the US was mapped into 5 seismic zones (0-4) with the following breakdown:

- **Zone 4 –** Highest hazard (California, parts of Alaska, Hawaii)
- **Zone 3 –** High hazard (Pacific Northwest, parts of Nevada/ Utah)
- **Zone 2A/2B –** Moderate hazard (Intermountain West, New Madrid, Charleston)
- **Zone 1 –** Low hazard
- **Zone 0 –** Very low hazard

These are still used in Probable Maximum Loss (PML) and Seismic Risk Analysis (SRA). ***But not for building design.***

For applications related to building design, the IBC does not use "zones" but seismic design categories (SDCs, A-F) that come from ASCE 7 which has been note earlier in this course. These are:

- SDC A – Very low hazard
- SDC B – Low hazard
- SDC C – Moderate hazard
- SDC D (D0, D1, D2) – High hazard
- SDC E – Very high hazard
- SDC F – Nearfault / special study zones

These categories are developed using:

- USGS seismic hazard maps
- Site soil class
- Building occupancy/importance

OTHER REGULATORY CLASSIFICATIONS

In most cases, the IBC and ASCE 7 are the primary design basis for architects and engineers. However, there are other agencies or institutions that provide classification categories for seismic design or response. It is quite possible that an architect's client may refer to one or more of these in their design program. Of course, code requirements cannot be reduced but they can be augmented. These have been summarized in tabular form for quick reference rather than narrative treatment.

Summary Table for Seismic Requirements Established by Various Agencies (United States only)

CATEGORY	*EXAMPLES*	*PRIMARY USERS*	*WHEN IT MATTERS*
FEDERAL REGULATIONS (EXECUTIVE ORDERS AND AGENCY STANDARDS)	EO 12699, 49 CFR 41	Federal agencies	Ensures seismic safety for federal buildings
NEHRP PROVISIONS	FEMA P750, P2082	Code developers, engineers	Basis for ASCE 7 & IBC seismic rules
DOD / UFC (UNIFIED FACILITIES CRITERIA)	UFC 331004, RC V	Military projects	Much stricter performance requirements
PBSD (PERFORMANCE-BASED SEISMIC DESIGN) FRAMEWORKS	FEMA P58, Tall Building Guidelines	Highperformance or complex buildings	Allows targeted performance levels
TSUNAMI DESIGN	ASCE 7 Ch. 6, FEMA P646	Pacific Northwest, Alaska	Adds tsunami loads & evacuation structures

32 USGS.gov

CATEGORY	EXAMPLES	PRIMARY USERS	WHEN IT MATTERS
NONSTRUCTURAL STANDARDS	FEMA E74, DoD RC V	Hospitals, labs, military	Protects equipment & life safety
LEGACY CODES	UBC Zones 0–4	Existing buildings	Needed for renovations & evaluations
FEMA SEISMIC DESIGN CATEGORY (SDC) MAPS	Classification of areas from A - F (same as ASCE 7)	Federal Agencies; Projects seeking Federal funding	Resilience planning; Hazard Mitigation planning
NRC (NUCLEAR REGULATORY COMMISSION)	Seismic categories: Category I – Safety related buildings -must remain functional.; Category II – Non-Safety related must maintain structural integrity though not functionality; Category NS – Non-Seismic.	Nuclear projects involving NRC approval	Safety of the public; preventing failure at a nuclear facility.

33 34 35 36

In addition to the above, another classification often mentioned is the Seismic Use Groups (SUG). These are classifications assigned to structures based on their occupancy, function, and the risk associated with their failure during an earthquake, defining the necessary level of seismic resistance. They are used in conjunction with seismic ground motion data to determine the Seismic Design Category (SDC). These range from Group I (standard) to Group III (essential facilities). These SUGs are related to the risk categories (I – IV) used in the IBC and ASCE 7 based on building function (IBC Table 1604.5 – Risk Category of Buildings and Other Structures)[37].

Below is a comparison of how the SUGs correspond to the IBC risk categories:

SEISMIC USE GROUP	ROUGH EQUIVALENT IN IBC/ASCE 7	TYPE OF OCCUPANCY
SUG I	Risk Category I–II	Standard occupancy
SUG II	Risk Category III	Essential facilities
SUG III	Risk Category IV	Critical or hazardous facilities

The descriptions for SUGs and Risk Categories are listed below:

SEISMIC USE GROUPS (SUG)

UFC documents define three main groups; each tied to the importance of the facility and the consequences of failure.

- **SUG I — Low Hazard / Standard Facilities**

These are buildings where failure would not cause significant loss of life, mission impact is minimal and no hazardous materials are present.

Typical examples:

- Warehouses
- Small administrative buildings
- Nonessential support structures

- **SUG II — Essential Facilities**

These are structures where failure would pose moderate risk to life, and mission impact would be significant. The facility must remain functional after an earthquake. Examples:

- Fire stations
- Emergency response facilities
- Key operational buildings
- Utility plants serving critical operations.

- **SUG III — High Hazard / Critical or Hazardous Facilities**

These are the highestimportance structures. They include facilities critical to mission continuation, buildings with no redundant backup or structures containing hazardous materials that could endanger life or the environment if released. Examples:

- Chemical storage facilities
- Highhazard industrial buildings
- Critical command centers

(Note: Some UFC documents further refine this group into subcategories such as IIIH for hazardous material intensive facilities.)

IBC /ASCE 7 SEISMIC RISK CATEGORIES

The IBC seismic risk categories I-IV classify buildings based on the potential risk to human life and the consequences of failure during an earthquake. Here's a summary of each category:

- **Risk Category I:** Buildings that represent a low hazard to human life in case of failure. Examples include agricultural facilities, certain temporary facilities, and minor storage building.
- **Risk Category II:** Buildings that are not classified in other categories and represent a normal risk to human life. This includes most residential, commercial, and industrial buildings.
- **Risk Category III:** Buildings that are essential facilities where failure could pose a substantial risk to human life or where the building is critical for post-disaster recovery. Examples include schools, community centers, and fire stations.
- **Risk Category IV:** Buildings that are critical facilities whose failure would pose a high risk to human life or have a significant impact on the community. These include hospitals, power plants, emergency response centers, and structures housing hazardous materials.

The above material shows that there are several regulations and standards that may need to be evaluated and which may impose requirements when designing a building that requires seismic design. This will depend primarily on the location and type of the project but also may need to consider the client's specific safety and/or risk considerations. It is beyond the scope of this course to investigate the various permutations arising from the intersectionality of the various regulations and codes. The intent is to provide architects with an awareness of the many regulations that should be filtered to ensure that

33 FEMA 389 - Primer for Design Professionals.
34 Overview of the Seismic Design Process Based on ASCE/SEI 7-22.
35 Introduction to 2024 Edition Seismic Design Category Maps.
36 Nuclear Regulatory Commission.gov
37 Table not reproduced due to ambiguity about Fair usage as defined by ICC for educational purposes.

proper consideration is being given. It is sometimes a misconception that seismic design is purely, or largely, a structural engineering concern. Both roles are critical, but they hold different, equally essential responsibilities in seismic design. Structural engineers are responsible for ensuring the building's safety, stability, and compliance with codes to withstand seismic forces, while architects define the structural configuration and layout, which fundamentally influences how the building responds to earthquakes.

In the next part of the course, we will look at how architects and structural engineers play their roles in developing solutions to design seismic resistant buildings.

END of PART 2

PART 2 REVIEW QUESTIONS

1. **The first U.S. state to adopt a seismic code was:**
   A. Oregon
   B. Colorado
   C. California
   D. Alaska

2. **The most significant standard for seismic design related to buildings is _____?**
   A. ASCE 7
   B. IBC Chapter 7
   C. BOCA 1943
   D. UN Building Council Sec. 33-2

3. **What is the popular name for the Circum-Pacific belt seismic zone?**
   A. Sino-American Plate
   B. Ring of Fire
   C. Trans Andean Zone
   D. Middle America trench

4. **How does the IBC guide seismic building design?**
   A. Defers to states
   B. Use of hazard classifications
   C. Use of seismic Zones
   D. Use of seismic design categories (SDCs)

5. **A building in SUG II would be classified as what type of occupancy?**
   A. Standard occupancy
   B. Non-combustible
   C. Essential facility
   D. Critical occupancy

PART 3 – SOLUTIONS: RESPONSES TO MITIGATE SEISMIC CHALLENGES

So far, we have reviewed how earthquakes come about and identified the main regulatory and scientific bodies that provide guidelines and/or mandates on how building designers must provide public safety for their projects. This Part will focus on how architects and engineers respond to the challenges posed by seismic risks in areas where earthquakes are a likely occurrence.

In earthquake prone areas of the world, builders have been aware of the threat for as long as humans started settling in these areas. Long before modern seismology, early civilizations tried to understand and predict earthquakes through observation, mythology, rudimentary instruments and even scientific thinking. Some of these methods are still applicable today and are in use in some parts of the world where the rigor and institutional resources are not available to the extent they are in wealthy, developed countries like the United States. In this section we will examine how we addressed earthquakes prior to contemporary technological benefits and how that process has changed in present times.

3.1. SEISMIC DESIGN IN PRE-INDUSTRIAL TIMES

As noted above, pre-industrial societies did endeavor to predict earthquakes based on a variety of ways as listed below:

1. **Observation of Animal Behavior:** Many ancient societies believed animals sensed earthquakes before humans. Some of these included:
   - Sudden agitation in dogs, horses, snakes
   - Mass animal migrations
   - Birds behaving erratically.

These ideas appear in multiple cultures and are mentioned in modern historical analyses of ancient prediction attempts.[38]

While not scientifically reliable, these observations show early attempts to link environmental cues to seismic events. These notions persist in folklore and cultural norms even today. It is not unusual to see these themes highlighted in movies with earthquake themes.

2. **Environmental and Atmospheric Signs:** Ancient observers often looked for unusual natural phenomena, including:
   - Changes in groundwater levels
   - Strange smells (e.g., sulfur)
   - Unusual weather or sky color
   - Ground cracking or rumbling noises.

Greek and Roman writers documented such "prodigies," interpreting them as precursors to earthquakes.[39]

3. **Mythological or Cosmological Models:** Before naturalistic explanations emerged, many civilizations explained earthquakes through myth:
   - Japan: A giant catfish (Namazu) thrashing underground
   - China: A cosmic dragon or turtle shifting
   - Greece: Poseidon striking the earth.
   - Native American cultures: Giant animals moving beneath the land.

These myths weren't predictions, but they shaped how societies interpreted seismic events.[40]

4. **Early Natural Philosophies (ProtoScience):** Some ancient thinkers tried to explain earthquakes using natural—not supernatural—causes.

38 forgottennexus.blogspot.com:/2026/02/ancient earthquake prediction methods
39 WorldHistoryEdu.com
40 projects.eri.ucsb.edu: A Brief History of Seismology to 1910

- Aristotle (4th century BCE) - Proposed that winds trapped in underground caverns caused the ground to shake. This was wrong, but it represented a shift toward naturalistic reasoning.[41]
- Greek & Roman Observers - Historical analyses show they sometimes recognized patterns such as:
  - Foreshocks
  - Groundwater anomalies
  - Atmospheric changes

Researchers have found that ancient Greeks and Romans occasionally made explicit predictions, but there is little evidence to support their accuracy.[42]

5. **EarthquakeDetecting Instrument (China, 132 CE):** One of the most remarkable innovations came from the Han Dynasty: Zhang Heng's Seismoscope, the first known instrument for seismic detection.
   - A large bronze vessel with dragon heads holding balls.
   - When a distant earthquake occurred, a ball would drop into a frog's mouth.
   - It could detect quakes hundreds of miles away.

This device didn't predict earthquakes, but it was the first scientific instrument for seismic detection, showing a sophisticated understanding of ground motion.[43]

6. **Pattern Recognition and Historical Memory:** Civilizations with long written traditions—China, Mesopotamia, Mesoamerica—sometimes tracked and kept records of:
   - Recurrence intervals
   - Seasonal patterns
   - Regional seismicity

These weren't predictions in the modern sense, but they helped communities identify which areas were more dangerous.

While pre-industrial societies used a combination of things noted above to attempt to understand and predict seismic activity, none of these societies had knowledge of some key scientific information that informs current understanding and technological sophistication. These are:

- A theory of plate tectonics
- Instruments to measure ground motion.
- Scientific models of stress accumulation
- Evidence based maps and more accurate historical trends to identify areas of high concern.

So, even though pre-industrial societies tried to predict earthquakes, their methods were largely observational or symbolic. And yet presently, even with the most advanced instruments and techniques in modern seismology, no scientist or agency can currently predict earthquakes – not the USGS, not any research group. Modern science states that a prediction must specify time, location, and magnitude, and no method (currently known) can do this.[44] We do, however, have a much better understanding about the nature and zonal geography of earthquakes and so can plan better, more effective solutions to resist the impact when an event does occur.

While the ability to predict remains almost as elusive now as it was in the past, societies that had to deal with seismic activity did not remain oblivious to the damage these incidents caused. Over time, many techniques were developed in various regions that established some successful techniques to mitigate the impact of earthquakes. We know that there were successful seismic resistant designs because many old structures have survived centuries of major earthquakes. General speculation is that in the absence of platetectonics theory, seismic codes, or reinforced concrete, what they used instead were intuitive, practical, and often creative seismicresistant design strategies. Some of the earliest solutions to withstanding earthquakes established are noted below:

1. **Flexible Timber Construction (Japan, China, Southeast Asia):** Wooden structures — especially multistory pagodas — have been demonstrably resilient. Some of their features include:
   1. Central wooden columns acting like a flexible spine.
   2. Interlocking joinery *(Dougong)* that allowed controlled movement.
   3. Lightweight materials reducing inertial forces.

These pagodas have survived dozens of major earthquakes because their frames sway instead of crack.[45]

2. **Polygonal Stone Masonry (Inca Empire, Peru):** Inca builders created some of the most earthquakeresistant stonework in history. These structures have the following characteristics:
   - Precisely cut, interlocking stones (sometimes called "Lego-Style") with no mortar.
   - Tapered blocks that fit like 3D puzzles
   - Walls leaning slightly inward for stability.
   - Stones that "dance" during shaking and settle back into place.
   - *Shicras*, which were woven fiber bags filled with stones, provide a flexible base that dissipated seismic energy.

These walls at Machu Picchu and Cusco routinely survive earthquakes that destroy modern buildings.[46]

3. **Base Isolation Using Sand, Gravel, or Timber Layers** (India, Middle East, Mediterranean): Some ancient builders intuitively used primitive base isolation, a technique that uses layers of sand, gravel, or charcoal beneath foundations; Timber beams embedded horizontally in masonry; and Foundations designed to absorb and dissipate seismic energy.

Northern India's ancient stone buildings show evidence of such layered foundations (Kath Kuni Architecture) that help absorb shaking.[47]

4. **Symmetry, Proportion, and Mass Distribution (Greece, Rome, Persia):** Ancient architects understood, through experience, that: i) Symmetrical layouts reduce torsion; ii) Regular column spacing distributes loads; and iii) Heavy lower stories + lighter upper stories improve stability.

These principles appear in temples, palaces, and fortifications across the Mediterranean.[48]

5. **EarthquakeAbsorbing Wall Systems (Various Civilizations):** Across cultures, builders developed wall systems that could flex or dissipate energy. Examples of these are:
   - Doublewythe walls with rubble cores.
   - Timberlaced masonry (e.g., *dhajjidewari* in the Himalayas)

41 Ibid
42 NASA Goodard Institute for Space Studies: Earthquake prediction in antiquity; Slothers, R. B., 2004.
43 WorldHistoryEdu.com
44 USGS.gov
45 curiosmos.com/earthquake-proof-stone-structures; Did ancient builders know how to earthquake-proof stone structures?
46 Ibid
47 The Ancient Architecture that Defies Earthquakes - Nautilus. nautil.us/the-ancient-architecture-that-defies-earthquakes-301285/
48 Exploring Ancient Techniques for Earthquake Resistance in Historical .... https://ancientrix.com/ancient-techniques-for-earthquake-resistance/

- Stone walls with internal voids to reduce mass.

These systems acted like early forms of energy dissipation.[49]

6. **Precision Stone Fitting Without Mortar (Inca, Aegean, Anatolia):** Some civilizations mastered mortarless construction with the following features:
   - Stones shaped to fit perfectly
   - Joints designed to **slide slightly** during shaking
   - No brittle mortar to crack

This technique is highlighted in studies of ancient "earthquakeproof walls" that still puzzle engineers today.[50]

As can be extrapolated from the above, even without modern scientific theory and tools, earlier builders used ***Empirical observation*** (learning from past collapses); ***Material intuition*** (using wood, stone and soil strategically); ***Redundancy and flexibility*** (allowing structures to move) and understanding the basic rules of ***Low stiffness & high ductility*** (the same principles used by modern engineers). With these methods many ancient structures have survived centuries and still outperform poorly designed modern buildings.

SOME EXAMPLES:

(these are some buildings that have survived for several centuries in some of the most active seismic areas of the world)

Tomb of CYRUS the GREAT (Pasargadae, Iran)[51]



Age: *~2,500 years*

Why it survived:

- *Massive stone blocks with tight joints*
- *A broad, stepped base that distributes seismic forces*
- *Simple, symmetric geometry that minimizes torsion*

This structure is widely cited as one of the oldest earthquakeresistant buildings still standing.

Source: Wikimedia Commons; Common usage

Historic Japanese Pagodas (Japan)



Age: *Many over 1,000 years old*

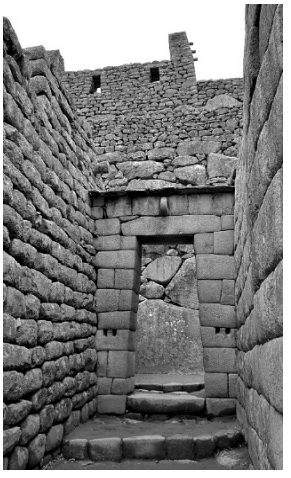
Why they survived:

- *Central "shinbashira" column acting like a flexible spine*
- *Interlocking wooden joints that slide instead of crack*
- *Lightweight timber construction that reduces inertial forces*

Remarkably, no traditional pagoda in Japan has ever collapsed from an earthquake, despite centuries of major seismic events.

Source: Wikimedia Commons; Common usage

Inca Stone Walls (Cusco, Peru)



Age: *500 – 700 years old*

Why they survived:

- *Polygonal stones cut with extreme precision*
- *Mortarless construction allowing stones to "dance" during shaking*
- *Slightly inclined walls for added stability*

These walls have withstood repeated earthquakes that destroyed much more recent nearby colonial era masonry structures.

Source: Wikimedia Commons; Common usage

Traditional Japanese Machiya & Minka Houses (Japan)



Age: *200 - 400 years*

Why they survive:

- *Flexible timber frames*
- *Lightweight infill walls*
- *Redundant bracing patterns*

This structures have survived repeated earthquakes demonstrating the power of ductility over mass strength.

Source: Free Stock Photo; Free to Use license

49 Exploring Ancient Methods for Earthquake Absorption in Historic .... https://archaforge.com/ancient-methods-for-earthquake-absorption/

50 The Ancient Earthquake-Proof Walls That Puzzle Engineers. https://www.youtube.com/watch?v=SNopZ0ovUtA

51 webuildvalue.com/en/facts/from-ancient-temples-to-futuristic-skyscrapers-10-extraordinary-earthquake-resistant-structures.html

Gutenberg Castle (Balzers, Lichtenstein)[52]



Age: *~800 years*

Why it survived:

- *Dense stone masonry with excellent mass distribution*
- *Elevated bedrock foundation*
- *Structural continuity that resists shear failure*

This is a frequently cited example of why certain medieval structures endure earthquakes so well.

Source: Wikimedia Commons; Common usage

Taj Mahal (Agra, India)



Age: ~400 years

Why it survived:

- *Floating Foundation: which prevents the building from cracking by absorbing shockwaves.*
- *Inclined Minarets: The four minarets are slightly tilted outwards to ensure they fall away from the central mausoleum.*

The Taj Mahal has survived for nearly 400 years in an area now considered part of seismic zone III

Source: Wikimedia Commons; Antrix3; Common usage, August 2016

3.2. POST INDUSTRIAL AND CONTEMPORARY SEISMIC DESIGN

With the advent of the Industrial Revolution (circa 1750 – 1914), two significant changes happened – i) people started to migrate to urban areas, creating a mass concentration of humanity in larger numbers than ever before, and ii) rapid advances in science, technology and research / education resulted in exponential expansion of scientific knowledge across the industrialized countries and then throughout the world. As population centers grew, many were in earthquake prone areas. It was only a matter of time that the impact of a major earthquake would expose the weaknesses of cities that had expanded hastily during industrialization with little to no regulatory oversight or even a comprehensive understanding of the risks faced by densely populated areas in the face of natural disasters. 1906 was the year and San Francisco was the American city where a massive earthquake [see inset below] struck that is widely considered the first to highlight the extreme vulnerability of modern, industrial urban cities to seismic events, especially regarding fire risks. It showed how high-density, interconnected urban systems could catastrophically fail, leading to widespread structural damage, fires, and infrastructure collapse.[53]

1906 San Francisco Earthquake[54]

The 1906 San Francisco earthquake is widely estimated to have had a magnitude of **7.9 M_w** (moment magnitude). While older sources often cite a Richter magnitude of 8.3, modern re-evaluation indicates 7.7 to 7.9 is more accurate, with the rupture extending nearly 300 miles along the San Andreas Fault.

Key details regarding the 1906 earthquake:

- **Time and Location:** April 18, 1906, at 5:12 a.m. PST, with an epicenter offshore just south of San Francisco.
- **Magnitude:** Generally cited as 7.9 **M_w**

Impact: The earthquake and ***subsequent fires*** destroyed over 80% of San Francisco, resulting in over 3,000 deaths and 200,000 people left homeless.

Fault Rupture: The tremor involved a massive rupture of the San Andreas Fault, spanning from San Juan Bautista to Humboldt County.

Scientific Significance: The event led to the development of the elastic rebound theory, forming the foundation of modern earthquake science



Source: Wikimedia Commons; San Francisco Earthquake 1906; Public Domain

In Part 1 of the course, we have traced how, after the San Francisco earthquake, industrialized countries with susceptibility to seismic activity started developing codes and standards to regulate how buildings needed to address earthquake and resulting fire risks. This brings us to the current state of seismic design, as it is applied in the United States. The codes and regulations have been discussed in Part 2. We will now look at the role of the major design professionals who are tasked with developing and constructing buildings and structures that respond to seismic threats and provide damage mitigation.

The development of an effective and responsive building that will perform as intended during a seismic event is the result of cooperation among and mutual respect for the skills of several professionals:

1. **Structural Engineer (SE) The Lead Seismic Designer**
   - **Role:** Primary authority on seismic design
   - **Responsibilities:**
     - Determine **Seismic Design Category (SDC)**, **Risk Category**, and **Response Modification Coefficients (R, Cd, Ω_o)**
     - Select the **lateral force–resisting system** (shear walls, braced frames, moment frames, base isolation, etc.)
     - Perform **ASCE 7 seismic analysis** (equivalent lateral force, modal response spectrum, nonlinear analysis)
     - Design and detail all structural components for **strength, stiffness, ductility, and drift limits.**

52 garlicsoda.com: 30 timeless buildings that have survived modern disasters

53 BGS - British Geological Survey

54 UC Berkeley Seismology Lab +4 and Wikipedia

- Coordinate with architects to avoid torsion, soft stories, irregularities.

In seismic design, the Structural Engineer is the "captain" of the team.

2. Geotechnical Engineer (GE) The Ground & Foundation Specialist

- **Role:** Defines the seismic hazard at the site.
- **Responsibilities:**
  - Determine **Site Class (A–F)**
  - Provide **geotechnical seismic parameters**:
  - S_s, S_1, F_a, F_v
  - Liquefaction potential
  - Lateral spreading, settlement, slope stability
  - Recommend **foundation type** (mat, piles, caissons, ground improvement)
  - Evaluate **fault rupture hazards** and **site amplification.**

Without accurate geotechnical input, the structural design is guesswork.

3. Architect — Geometry, Massing, and Irregularity Control

- **Role:** Shapes the building's seismic behavior.
- **Responsibilities:**
  - Control **building configuration**, which is the #1 driver of seismic performance.
  - Avoid:
  - Soft/weak stories
  - Torsional irregularities
  - Vertical discontinuities (an abrupt change or break in the structural, geometric, or stiffness characteristics of a building along its vertical axis (height).
  - Heavy roofs or appendages
  - Coordinate **nonstructural seismic design** (ceilings, facades, partitions, equipment anchorage)
  - Ensure code compliance for **egress, fire separation, and drift compatibility.**

Architects don't calculate seismic forces, but they determine whether the building will behave well or fight the earthquake.

4. MEP Engineers — Nonstructural Seismic Protection

- **Role:** Protect systems that must remain functional
- **Responsibilities:**
  - Design seismic bracing for:
    - Mechanical equipment
    - Electrical gear
    - Fire protection systems.
    - Piping, ducts, conduits
    - Ensure **anchorage** meets ASCE 7 Chapter 13
    - Coordinate with structural engineer for attachment points.

Nonstructural failures cause most earthquake damage and downtime.

5. Civil Engineer — Site & Lifeline Resilience

- **Role:** Ensure the site and utilities survive shaking
- **Responsibilities:**
  - Design **site retaining walls**, **grading**, **drainage**, **utility lines.**
  - Address **soil–structure interaction** with SE and GE
  - Ensure **lifelines** (water, sewer, storm, gas) have seismic flexibility.

6. Seismic/Structural Peer Reviewer (SPR)

- **Role:** Independent expert review
- **Responsibilities:**
  - Required for **highrise**, **essential facilities**, or **performancebased design.**
  - Validate modeling, assumptions, detailing, and performance objectives.
  - Provide thirdparty oversight for jurisdictions like LA, SF, Seattle.

7. Seismic Hazard Specialist / Seismologist (for complex projects)

- **Role:** Advanced hazard characterization
- **Responsibilities:**
  - Develop **sitespecific ground motion studies.**
  - Model nearfault effects, basin amplification, longperiod demands.
  - Essential for tall buildings, hospitals, nuclear facilities, and baseisolated structures.

8. Building Official / Authority Having Jurisdiction (AHJ)

- **Role:** Code enforcement
- **Responsibilities:**
  - Approve seismic design criteria.
  - Review structural calculations and drawings.
  - Oversee special inspections and testing.

9. Special Inspector & Testing Agency

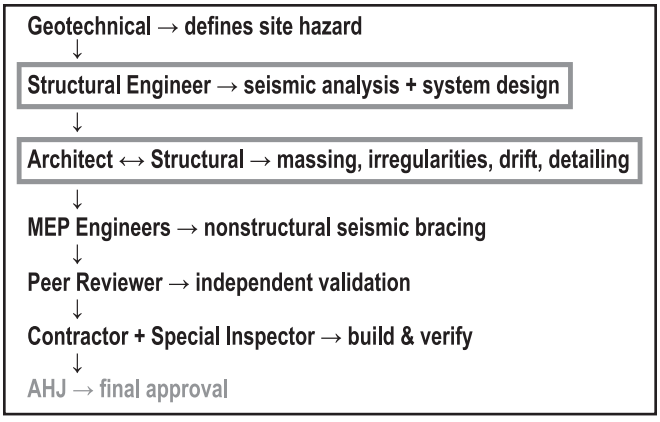
- **Role:** Ensure seismic detailing is built correctly.
- **Responsibilities:**
  - Inspect welds, anchors, rebar, concrete, shotcrete, masonry.
  - Verify seismic bracing for nonstructural components.
  - Required by IBC Chapter 17

Even a perfect seismic design fails if it is not built as detailed.

10. Contractor & Subcontractors

- **Role:** Execute the seismic detailing in the field.
- **Responsibilities:**
  - Install holddowns, collectors, boundary elements, anchors.
  - Coordinate sequencing to avoid weakening the structure.
  - Maintain quality control during construction.

To deliver an effective seismic solution all the members of the "Team" as noted above work together in sequence. Below is a simplified diagram showing how each member of the design and delivery team connects with the others.



Since this course is primarily developed for architects, we will examine specifically how the Architect's role is carried out, and which parts of the many codes and regulations require an architect's attention. The role of the architect cannot be understated even though the primary seismic design responsibility is that of the structural engineer who also assumes the primary liability in case of design failure. However, the Architect shares some of the liability and many of the responsibilities as noted above. The main reason architects have a significant influence on the seismic performance of the design is because even though the structural engineer defines the "Skeleton" of the building, performs the safety analyses and ensures structural integrity, it is the Architect who determines the shape, layout, and structural configuration, which are primary factors in seismic performance. They also integrate structural requirements with aesthetic and functional needs and make material specifications that affect the building's mass and flexibility. Because of these critical factors that the Architect controls, architects and structural engineers cannot work in isolated silos.

When it comes to code compliance, the bulk of the burden falls on the structural engineer. However, there are parts of the IBC / ASCE 7 that the Architect needs to be familiar with for doing their part. The table below summarizes the key portions of the code that apply to architects:

Key ASCE 7 Chapters

ARCHITECT RESPONSIBILITY	*ASCE 7 CHAPTER*
Control irregularities	Ch. 12.3
Drift compatibility for cladding	Ch. 12.12.5
Nonstructural components (coordination)	Ch. 13
Architectural components (ceilings, partitions, doors, windows)	Ch. 13.5 – 13.6

The involvement of the Architect is also continuous throughout the design and construction of the project. Below is a summary of the Architect's role in seismic design across the phases of a project:

PHASE	*ARCHITECT RESPONSIBILITIES*
CONCEPTUAL	Massing, symmetry, vertical continuity, avoid soft stories.
SCHEMATIC DESIGN (SD)	Coordinate structural grids, shear wall placement, diaphragm layout.
DESIGN DEVELOPMENT (DD)	Detail cladding joints, drift allowances, façade anchorage.
CONSTRUCTION DOCUMENTS (CD)	Coordinate with SE/MEP on penetrations, anchorage, and ceilings.
CONSTRUCTION ADMINISTRATION (CA)	Review submittals, ensure seismic detailing is not valueengineered out.

Another indicator of the importance of the architect's role in seismic design, several US states have special seismic design requirements that impact the licensing and / or the practice of architecture. These tend to be states with high seismic risk zones as stated below:

- **California:** Has extensive seismic design requirements under the California Building Code (CBC), which incorporates and often exceeds ASCE 7 seismic provisions. The CBC is more stringent than the standard International Building Code (IBC) used elsewhere, particularly for hospitals. Architects must be familiar with these for licensing and practice.[55] California also specifically mandates a California Supplemental Exam (CSE) focused on seismic safety and design.
- **Alaska:** Due to high seismic risk, Alaska has specific seismic design provisions architects must follow.
- **Washington:** The state enforces seismic design requirements aligned with ASCE 7 and IBC, with additional local amendments.
- **Oregon:** Similar to Washington, Oregon has seismic design requirements that architects must consider.
- **Nevada:** Has seismic provisions due to its seismic activity.
- **Hawaii:** Has seismic design requirements due to its location on tectonic boundaries.

Other states with notable seismic provisions include Utah, Idaho, and Montana, but the level of special licensing or design requirements for architects varies.

Architect licensing boards in these states often require architects to demonstrate knowledge of seismic design principles relevant to their jurisdiction, either through education, exams, or continuing education.

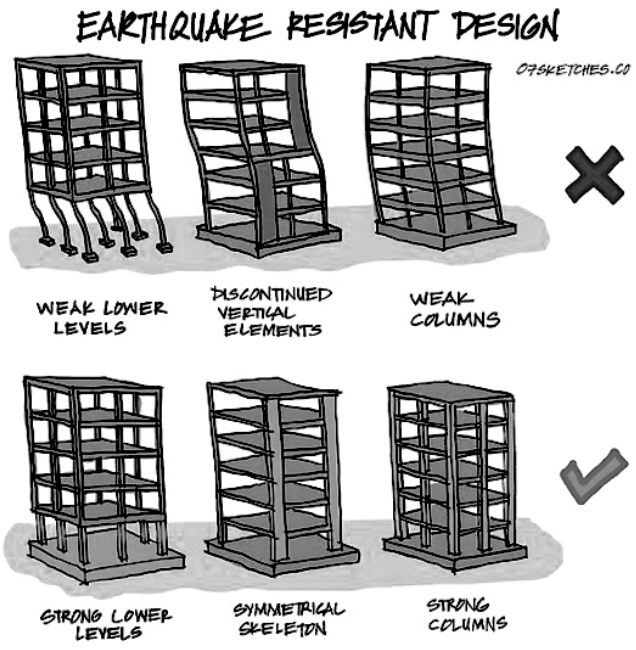
3.3. SEISMIC DESIGN AND ARCHITECTURAL RESPONSES

The structural engineer bears the major responsibility to ensure a building responds to earthquakes without collapsing and maintains the designed degree of survivability after the seismic event. But the architect must make certain that the non-structural elements also survive and maintain the desired level of functionality. It is pointless for a building to remain structurally sound but have all its interior walls, exterior skin and penetrations and mechanical / electrical systems rendered useless. Therefore, the architectural response must work with the structural response. For the degree of movement that the structure permits, architectural detailing, connections and supports must allow for the same level of flexibility.

For the building skeleton, the illustration below is a simple guide about the main elements of earthquake design:

NOTE: These are diagrammatic sketches intended to illustrate principles rather than literal solutions and should be viewed in that context.

55 Google AI



Source: NMR Glass and Mirror Facebook Post. Courtesy 07Sketches by Bhupesh Kumar.

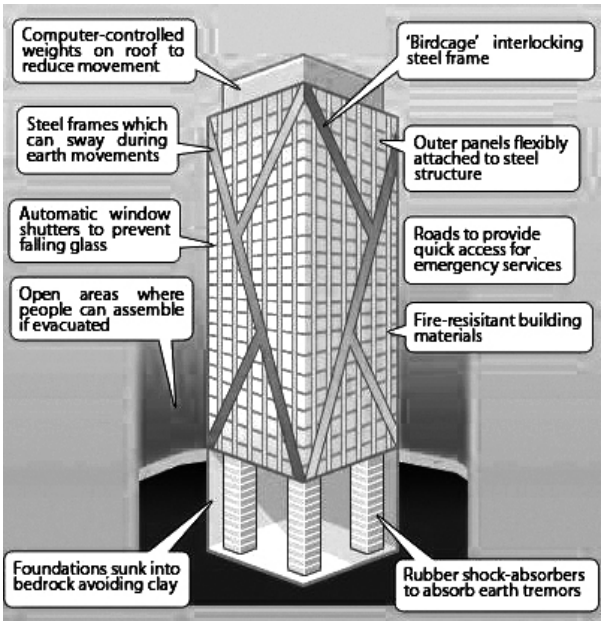
Seismic design response focuses on creating structures that can absorb, dissipate, and redirect the energy of an earthquake to prevent collapse and ensure occupant safety.

This differs from standard structural design which focuses on resisting gravity. Seismic design treats the building as a dynamic system that must "dance" with the ground's movement [56]

For "seismic architecture" or "earthquake architecture"[57] design, the main considerations are:

- **Building Massing and Symmetry:** Avoiding irregular shapes and asymmetry that can cause torsional forces.
- **Vertical and Horizontal Continuity:** Ensuring load paths are continuous to transfer seismic forces effectively.
- **Structural System Coordination:** Placement and coordination of shear walls, braced frames, and diaphragms with architectural layouts.
- **Soft Story Avoidance:** Designing floors with consistent stiffness and strength to prevent weak stories.
- **Drift Compatibility:** Allowing for lateral movement without damage to cladding, partitions, and nonstructural components.
- **Façade and Cladding Anchorage:** Detailing connections to accommodate seismic movement.
- **Partition and Ceiling Systems:** Designing nonstructural elements to accommodate seismic forces and movement.
- **Penetrations and Openings:** Coordinating locations and detailing around structural elements to maintain integrity.
- **Doors and Windows:** Focusing on flexibility, material resilience, and secure anchoring to prevent failure during intense ground shaking.
- **Nonstructural Components:** Including mechanical, electrical, plumbing (MEP) equipment bracing and anchorage.
- **Foundation and Soil Interaction:** Architectural considerations for foundation types and site conditions affecting seismic response.

Seismic Effects on Structures and Responses



Source: aboutCivil.com [58]

SEISMIC DESIGN APPROACHES AND MECHANISMS

In order to develop design solutions, some of the main techniques used are described below [59]*(While the primary system is structural, the choice is usually the result of collaboration between the architect and structural engineer so that the structural system supports the buikding configuration and functional needs)*:

Structural Systems:

- ***Diaphragms***: Floors and roofs can be used as rigid horizontal planes, or diaphragms, to transfer lateral forces to vertical resisting elements such as walls or frames.

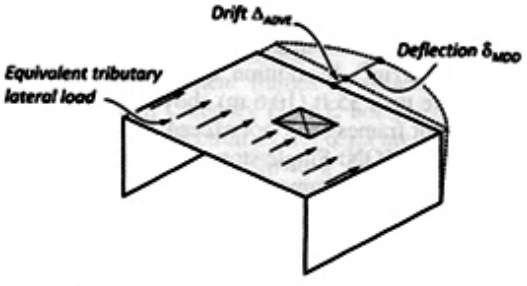


FIGURE 12.3-1 Flexible Diaphragm

Source: theStructuralEngineer.info / education/diaphragms. Illustration credit: Bentley Systems

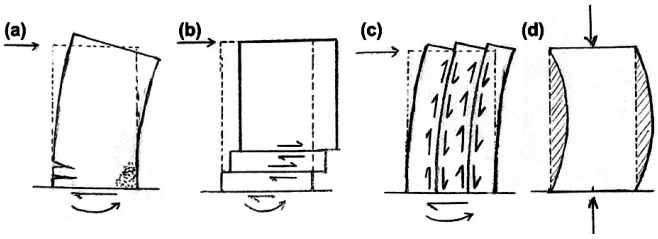
56 fiveable.me/earthquake-engineering/unit-6

57 [NOTE: *These terms were first introduced in 1985 by Robert Reitherman. The phrase "earthquake architecture" is used to describe a degree of architectural expression of earthquake resistance or implication of architectural configuration, form or style in earthquake resistance.*] – Google AI

58 aboutCivil.com: Earthquake Resistant Building Design by Haseeb Jamal; May 02, 2017

59 wbdg.org: seismic design principles

- ***Shear Walls***: Strategically located stiffened walls are shear walls and are capable of transferring lateral forces from floors and roofs to the foundation.

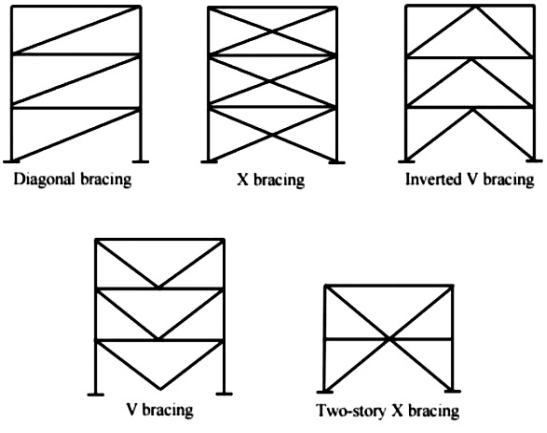


Failure mechanisms of shear walls.

(a) *flexural failure,* ***(b)*** *horizontal shear,* ***(c)*** *vertical shear,* ***(d)*** *buckling.*

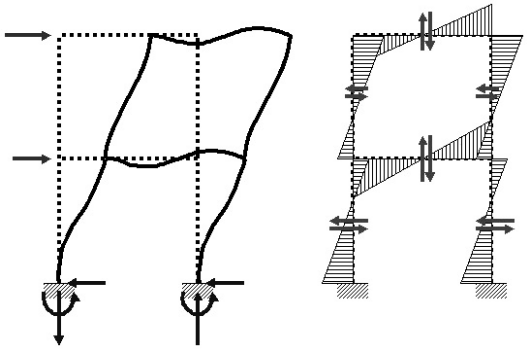
Source: Wikimedia Commons – Fair Usage.

- ***Braced Frames*:** Vertical frames that transfer lateral loads from floors and roofs to foundations. Like shear walls, Braced Frames are designed to take lateral loads but are used where shear walls are impractical.



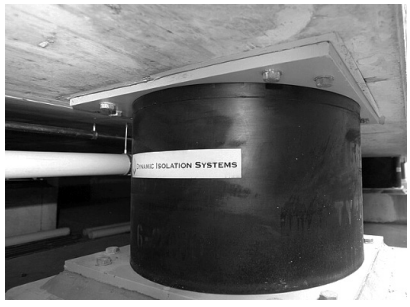
Source: BEATO Consulting Engineers, LLC; Blogpost. [60]

- ***Moment-Resistant Frames*:** Column/beam joints in moment-resistant frames are designed to take both shear and bending thereby eliminating the space limitations of solid shear walls or braced frames. The column/beam joints are carefully designed to be stiff yet to allow some deformation for energy dissipation taking advantage of the ductility of steel (reinforced concrete can be designed as a Moment-Resistant Frame as well).



Source: Wikimedia Commons – Fair Usage. Rahmen Kouzou

- ***Energy-Dissipating Devices*:** Making the building structure more resistive will increase shaking which may damage the contents or the function of the building. Energy-Dissipating Devices are used to minimize shaking. Energy will dissipate if ductile materials deform in a controlled way. An example is Eccentric Bracing whereby the controlled deformation of framing members dissipates energy. However, this will not eliminate or reduce damage to building contents. A more direct solution is the use of energy dissipating devices that function like shock absorbers in a moving car. The period of the building will be lengthened, and the building will "ride out" the shaking within a tolerable range.



Base isolation dampers used to improve seismic performance.

Source: Wikimedia Commons – Fair Usage.

- ***Base Isolation and Dampers*:** This seismic design strategy involves separating the building from the foundation and acts to absorb shock. As the ground moves, the building moves at a slower pace because the isolators dissipate a large part of the shock. The building must be designed to act as a unit, or "rigid box", of appropriate height (to avoid overturning) and have flexible utility connections to accommodate movement at its base. Base Isolation is easiest to incorporate in the design of new construction. Tall buildings cannot be base-isolated or they would overturn. Being very flexible compared to low-rise buildings, their horizontal displacement needs to be controlled. This can be achieved using ***Dampers***, which absorb a good part of the energy, making the displacement tolerable. Retrofitting existing buildings is often easier with dampers than with base isolators, especially if the application is external or does not interfere with the occupants.

  There are many types of dampers used to mitigate seismic effects, including:

  - Hysteric dampers utilize the deformation of metal parts.
  - Visco-elastic dampers stretch an elastomer in combination with metal parts.
  - Friction dampers use metal or other surfaces in friction.
  - Viscous dampers compress a fluid in a piston-like device.
  - Hybrid dampers utilize the combination of elastomeric and metal or other parts.



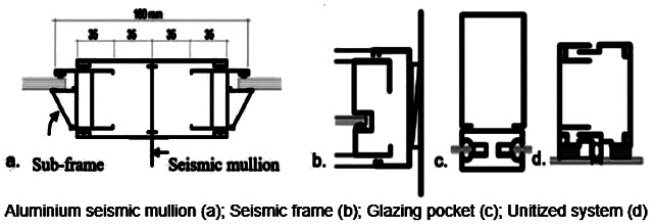
The Tuned Mass Damper in Taipei 101.

Source: Wikimedia Commons – Taipei 101 Tuned Mass Damper.png and photograph by author – 2025

60 beatoconsultingengineers.com/blog: "seismic design of steel concentrically braced-frames"; May 27, 2021

Architectural Systems:

- **Flexible Joints and Seismic Gaps:** Designed to accommodate movement between building sections or components.
- **Base Isolation Systems:** Architectural integration of isolation bearings to reduce seismic forces transmitted to the structure. (see above discussion)
- **Reinforced Openings:** Doors and windows detailed to maintain structural integrity during seismic events.



Aluminium seismic mullion (a); Seismic frame (b); Glazing pocket (c); Unitized system (d)

Source: Researchgate.net

- **Seismic-Resistant Façade Systems:** Cladding and curtain walls designed with anchorage and flexibility to withstand seismic drift.



UC Berkeley University Hall retrofit with seismic façade; Source: Interactive Resources

- **Nonstructural Anchorage:** Secure attachment of ceilings, partitions, and MEP equipment to prevent damage or hazards.
- **Redundancy and Regularity in Layout:** Architectural planning to avoid irregularities and ensure balanced seismic response.
- **Avoidance of Soft Stories:** Design strategies to prevent weak floors, often by distributing shear walls or frames evenly.
- **Roof Diaphragm Design:** Roof structures designed to transfer lateral forces effectively. (see discussion on diaphragms earlier)
- **Foundation Detailing:** Architectural coordination with foundation design to accommodate seismic loads and soil-structure interaction.
- **Tensile Structures:** These structures use flexible steel reinforcement, braces, and specialized materials to handle the stretching forces (tension) created during earthquakes, preventing brittle failure. By combining high-tensile steel with concrete, these systems allow buildings to sway, absorb seismic energy, and maintain structural integrity rather than cracking.[61]
- **Fabric or Tension Fabric Seismic Structures:** These are highly resilient, lightweight buildings featuring engineered fabric stretched over rigid steel frames. Their inherent flexibility, low mass, and ductile design allow them to absorb and dissipate seismic energy without failing, making them ideal for high-risk earthquake zones and providing a durable, cost-effective alternative to traditional, rigid concrete or steel buildings.[62]



(Image courtesy of Legacy Building Solutions.) Explosives storage for a mining facility in the Atacama Mountains, Chile.

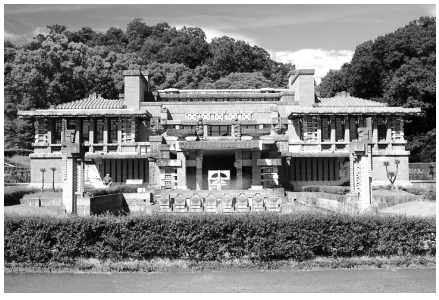
These examples illustrate how seismic design principles translate into tangible architectural features that enhance building resilience.

Given the many constraints that seismic design imposes, this does not imply that all seismic resistant buildings end up being boring and rigid. In fact, some very creative and innovative designs have been built that took their forms and responses to functional requirements directly from the seismic responses required. Below are some examples of unique buildings where architects developed very innovative and dramatic solutions in response to earthquake design:

Imperial Hotel (1923) by Frank Lloyd Wright.

Seismic Qualities:

- Famously survived the 1923 Great Kanto Earthquake with minimal damage.
- Utilized a **"floating" foundation** on soft mud. interconnected
- Cantilevered, balanced floors
- Structural concrete
- Employed flexible, curved pipes for utility joints to dissipate earthquake energy
- Used lightweight fire-resistant materials



Source: Wikimedia Commons; Common Usage; Imperial Hotel in Meiji Mura 2022.jpg

Petronas Towers, Kuala Lumpur Malaysia by Cesar Pelli

Seismic Qualities:

- The towers utilize high-strength, reinforced concrete to create a stiffer structure that is more effective at reducing sway
- **Tube-in-Tube Design**: An inner core wall and an outer ring of columns work together as a rigid tube-in-tube system, which resists lateral forces from both winds and earthquakes
- **Skybridge Connection:** Located 170 meters above ground, the 58.4-meter-long skybridge is designed to handle the movement of the two towers, withstanding tremors

61 ferrofabrikltd.com/ "The Role of High Tensile Reinforcing Bars in Earthquake-Resistant Structures"; October 20, 2023

62 domeshelter.com.au; "Are Fabric Structures Effective in Earthquakes?; December 22, 2022



Source: Author – muhammad a siddiqui © 2019

Palazzetto dello (1957), Rome, Italy by Pier Luigi Nervi

Seismic Qualities:

- The building features a 61-meter diameter ribbed concrete shell dome constructed from 1,620 prefabricated "ferrocement" pieces.
- This foundation is designed to absorb the strong horizontal and vertical forces, which is critical for earthquake resistance.
- **"Isostatic" Design:** a technique that inherently provides superior performance against lateral loading conditions, such as those during an earthquakes



Source: Wikimedia Commons; Public Domain; Palazzetto dello Sport di Pier Luigi Nervi

Transamerica Pyramid (1969), San Francisco by William Pereira

Seismic Qualities:



Source: Wikimedia Commons Public Domain

The pyramid shape and wide base lower the center of gravity, increasing stability against horizontal and vertical seismic forces.

Foundation: The building sits on a 9-foot-thick concrete mat, placed during a 3-day continuous pour, and reaches 52 feet deep.

Truss System: A specialized, high-strength truss system extends from the ground up to the 45th floor, enabling the building to resist extreme torsional (twisting) forces.

Flexibility: The structure is designed to sway or "bend" during an earthquake rather than remain rigid, which prevents cracking.

Performance: During the 1989 magnitude 7.1 Loma Prieta earthquake, the building swayed more than 12 inches but sustained no damage

101 Taipei (2004), Taipei, Taiwan by C.Y. Lee and Partners



Source: Author – Muhammad A Siddiqui © 2025

Seismic Qualities:

Tuned Mass Damper (TMD): A 660-ton (5.5-meter diameter) steel sphere suspended between the 87th and 92nd floors acts as a pendulum, reducing building sway by up to 40%.

Foundation: 380 concrete piles, driven 262 feet into the ground with the deepest extending 100 feet into the bedrock, securely anchor the tower.

Structural Flexibility: The tower uses a high-performance, flexible steel-and-concrete structure, allowing it to sway during earthquakes and typhoons while maintaining integrity.

Mega-Frame System: The structural design incorporates a braced-frame core, perimeter moment frames, and outrigger trusses to handle heavy lateral loads.

Seismic Design Standards: The tower was designed to withstand the strongest earthquakes expected in a 2,500-year cycle.

Dynamic Behavior: The building's translational modal frequencies range from 0.15 Hz to 0.78 Hz, with higher temperatures increasing frequency and higher wind speeds decreasing it.

Apple Park, Cupertino, California by Norman Foster & Partners

Seismic Qualities:

- The building sits on 700 base isolators (also called "saucers"), each 7ft. in diameter (wt. 15,000 lbs) *{Engineering News Record, ENR}*
- The "campus" building can shift up to 4 ft on those saucers. *{Business Insider}*



Source: Wikimedia Commons; Creative Commons; Apple Park.jpg. January 22, 2025

The above are just a sampling of prominent, architecturally significant and ground-breaking designs which included effective seismic responses in their design. There are numerous other examples. In fact, it can be argued that almost all recent major buildings along the US west coast cities are seismic solutions since they are built to comply with building codes.

So, while seismic design is engineering centered, the architectural contributions cannot be understated. In the next part we will look at how seismic design is set to evolve in future as part of broader architectural and regulatory focus to make buildings not simply able to survive earthquakes but to become part of an adaptable and resilient design approach.

END PART 3

PART 3 REVIEW QUESTIONS

1. **In pre-industrial times seismic design was:**
   A. Ignored
   B. Based on observations, trial and error and pattern recognition
   C. Based on scientific calculations
   D. Developed using plate tectonic theory

2. **Which of the following is a characteristic of why Gutenberg Castle in Lichtenstein and similar medieval structures have survived seismic events?**
   A. Flexible timber frames
   B. Inclined turrets
   C. Dense masonry with excellent mass distribution
   D. Polygonal stones with precision cuts

3. **A foundational theory of modern earthquake science is _____?**
   A. Zonal relativity theory
   B. Elastic rebound theory
   C. Seismic Uplift theory
   D. None of the above

4. **Which chapter of the IBC requires special inspection and testing for seismic structures?**
   A. 12
   B. 32
   C. 21
   D. 17

5. **Which of the following is not a consideration for seismic architecture?**
   A. Building color
   B. Doors and windows
   C. Façade and Cladding Anchorage
   D. Drift Compatibility

PART 4 – FUTURE: BEYOND SURVIVING EARTHQUAKES TO ADAPTABILITY

Building codes and governmental agencies are currently the primary guardians of ensuring that structures in seismic zones respond appropriately to the severity of the region and type of occupancy. However, in recent years, seismic design is shifting from a codeminimum, forcebased mindset towards an adaptive, "intelligent", and sustainabilitydriven resilience. The direction seems to indicate that buildings will increasingly sense, respond, and r**ecover rather than simply resist**. In this part we will look at developments and trends that reflect what researchers, architects, and engineers are already exploring and deploying.

4.1. MAJOR TRENDS AND DIRECTIONS SHAPING THE FUTURE OF SEISMIC DESIGN

1. **Smart, Sensor Rich, A.I. Enabled Structures:** Buildings are moving toward continuous, real time seismic awareness.
   - **IoT *(Internet of Things)* sensor networks** track drift, acceleration, and structural health during and after earthquakes.
   - **AI assisted modeling** improves prediction of building response and optimizes design decisions.
   - **Machine learning based damage detection** supports rapid post event re-occupancy.

These trends are highlighted in emerging "smart seismic design" approaches that integrate AI and IoT monitoring.[63]

2. **Advanced Materials That Adapt or "SelfHeal":** Material science is accelerating seismic innovation.
   - **Shapememory alloys** can recenter structures after shaking.
   - **Highperformance composites** reduce mass and increase ductility.
   - **Selfhealing concrete** minimizes longterm degradation.

63 buildings.com; "Next-Gen Seismic Design: How Smart Tech Is Reinventing Earthquake-Resistant Buildings"; Emily Newton; May 27, 2025

Current research on new materials for highrise seismic design shows rapid progress in this area.[64]

3. **NextGeneration Energy Dissipation and Isolation:** Traditional base isolation is evolving into more sophisticated systems.
   - **Hybrid base isolation** combines elastomeric bearings with sliding or damping mechanisms.
   - **Seismic cloaking** concepts aim to redirect seismic waves around structures.
   - **Tuned mass dampers** are becoming smarter and more adaptive, especially in tall buildings.

These technologies are increasingly central to nextgen earthquakeresistant buildings.65

4. **PerformanceBased and ResilienceBased Design:** Codes are shifting from "life safety only" to functional recovery.
   - Buildings are expected not just to avoid collapse but to resume operations quickly.
   - Performancebased design frameworks allow tailored seismic objectives for hospitals, data centers, and highrise towers.
   - Urban resilience planning integrates buildinglevel performance with communityscale recovery.

5. **Computational Modeling and Digital Twins:** virtual replicas (digital twins) of buildings are becoming part of seismic engineering workflows. These models perform the following:
   - Simulate structural response under multiple earthquake scenarios.
   - Integrate sensor data to update models continuously.
   - Support predictive maintenance and rapid postevent assessment.

6. **Integration of Sustainability and Seismic Resilience:** Future seismic design aims to balance carbon reduction with structural safety.
   - Lowcarbon materials and optimized structural systems reduce environmental impact.
   - Energydissipating devices and base isolation reduce repair needs and embodied carbon over a building's life.
   - Sustainable seismic design is emerging as a unified discipline.[66]

7. **Architectural Innovation for Seismic Safety:** Architects are increasingly shaping seismic performance through form, massing, and material choices.
   - New architectural strategies emphasize redundancy, controlled deformation, and distributed damping.
   - Innovations in façade systems, cores, and modular construction are improving resilience.

These trends reflect a broader architectural shift toward seismicaware design.[67]

8. **CommunityScale and Urban Seismic Resilience:** The underlying theme here is that the future of seismic design extends beyond individual buildings.
   - Cities are adopting seismic micro-zonation, lifeline resilience planning, and regional recovery modeling.
   - Infrastructure, utilities, and buildings are being designed as interconnected systems.
   - Policy is moving toward functional recovery mandates, already emerging in some jurisdictions, especially where Resilient Design is gaining roots such as in California.

The above are the trends that will shape the application of seismic design in the coming years and decades. There are specific implications for structural engineers and architects as we will explore in the next section. Nonetheless, in general, the broader implications for seismic design across all professions and regulatory bodies are likely to emphasize the following attributes:

a. Datadriven decisionmaking.
b. Adaptive systems rather than static resistance.
c. Sustainable, lowcarbon structural strategies.
d. Rapid recovery and continuity of operations.
e. Integration of smart technologies from concept through lifecycle.

4.2. EVOLUTION OF SEISMIC DESIGN AND IMPACT ON DESIGN PROFESSIONALS

The design professions most likely to be impacted by the trends described above will be structural engineers and architects. Since the focus of this course is on architects, those impacts will be addressed in greater detail. Still, the main likely effect on structural engineering practice needs to be noted and understood by architects because as the roles of any of the "team" members (as noted earlier in then course) affects all other members and adaptation is critical.

IMPACT ON STRUCTURAL ENGINEERING PRACTICE

The role is expanding from "designing for forces" to designing for resilience, recovery, and lifecycle performance.

Engineers are likely to do more of the following:

- Use nonlinear analysis as a standard tool.
- Collaborate with A.I. driven monitoring systems.
- Design structures that can be repaired quickly or avoid damage altogether.
- Integrate sustainability metrics into seismic system choices.
- **Enhanced Geotechnical–Structural Integration:** The boundary between geotechnical and structural engineering is tightening. This integration reduces uncertainty and improves performance predictions.
  - Soil–structure interaction (SSI) is being modeled more accurately with nonlinear analysis.
  - Sitespecific ground motion simulations are replacing generic spectra in many regions.
  - Foundation systems (e.g., rocking foundations, isolation at the foundation level) are becoming part of the seismic system rather than an afterthought.

IMPACT ON ARCHITECTURAL PRACTICE

Perhaps the most significant shift in seismic design will be in the way architects practice. One reason for this is that architectural practice in general is undergoing a sort of revolution, arguably a paradigm shift from a myopic focus on solving a functional program for a single building to a more gregarious role where considerations of sustainability and resilience are requiring architects to think beyond simply solving the client's program to assessing how their designs

64 sciencepublishinggroup.com; "Advances in Seismic Design for High-Rise Buildings: A Systematic Review of New Techniques and Materials"; *American Journal of Civil Engineering (Volume 13, Issue 2)*; Girmay Mengesha Aznaw; 22 April, 2025

65 buildings.com; "Next-Gen Seismic Design: How Smart Tech Is Reinventing Earthquake-Resistant Buildings"; Emily Newton; May 27, 2025

66 icsecm.org; "Innovations in Seismic Design for Sustainable Structures"; 07/05/2025

67 Architizer.com; "Seismic Safety: Architectural Innovations in Earthquake Zones"; Eric Baldwin;

impact and are impacted by their environment – natural and human created. This is not to say that architects' primary responsibility will move away from their clients. On the contrary, the convergence of regulatory restructuring towards sustainability and resilience coupled with the economic realities of the cost of poor design will force and / or influence building owners (clients) to either require or at least accept the shift. Accessibility, energy efficirncy and even seismic design in its current form are all examples of how shifts in priorities and codification of these leads to changes in how buildings are designed and how the professional practices morph in response. The dramatic changes in the way performance based regulatory thinking and Artificial Intelligence supported technologies and tools are starting to shape the practice discourse gives clear indications that all aspects of the practice of architecture will be restructured – not unlike how CAD and the PC replaced the drafting board and the paper practice binders. Here are some of the likely ways in which the role of the architect is changing relative to seismic design:

A. Perhaps most importantly, Architecture must **integrate resilience from the earliest concept stage**. Emerging research emphasizes that architectural decisions – geometry, mass distribution, façade systems – directly influence seismic behavior. Architects are expected to design with seismic forces in mind from the outset, not as a late coordination step.[68] This means that architects will increasingly be expected to understand seismic behavior at a conceptual level and collaborate earlier and more deeply with structural and geotechnical engineers.

B. **Performance based design requires deeper collaboration** with the "team": As performancebased and functionalrecovery standards grow, architects must coordinate closely with structural engineers to meet specific performance targets. This shifts practice toward early multidisciplinary modeling sessions, iterative formfinding that balances aesthetics, drift limits, and damping strategies. In addition, it requires designing nonstructural components – ceilings, partitions, cladding – to meet seismic performance goals.

C. **Nextgeneration seismic systems:** For architects, this means greater freedom to explore expressive forms because advanced damping and isolation can manage irregularities. New façade and envelope strategies to enable integration of sensors or adaptive components. These can lead to options to design buildings that communicate their "health" to occupants and owners.

D. **Architecture tied to community resilience:** In seismic regions, buildings are expected to serve as symbols of safety and recovery. Architectural publications highlight that earthquakeresistant design is becoming a cultural and civic responsibility, not just a technical one.[69] This affects practice by elevating resilience as a visible design value and encouraging architects to design public spaces and forms that support postevent gathering and recovery. By integrating seismic resilience into the narrative of the project, similar to sustainability.

E. **Sustainability and seismic resilience are converging:** Perhaps, even merging as contemporary architecture increasingly integrates lowcarbon materials with seismic performance goals. For example, mass timber systems (CLT walls, braced frames) are being tested for seismic regions; lightweight, ductile materials reduce seismic forces and embodied carbon, and lifecycle monitoring supports longterm sustainability by reducing repair needs. This means that Architects must now evaluate how material choices affect both carbon footprint and seismic behavior.

F. **Use of "Digital Twins":** Virtual models updated by realtime sensor data are becoming part of seismic design and building management. For architects, this means designing buildings with embedded monitoring infrastructure and considering how operational data will influence future renovations or adaptive reuse. This expands the architect's role to involve participating in longterm resilience planning beyond construction.

G. **Urban-scale seismic resilience and site design:** As cities adopt microzonation* and resilience planning, architects must respond to sitespecific seismic conditions. This impacts site planning, orientation, and massing decisions and the integration of open spaces that can serve as emergency gathering areas. It also fosters coordination with lifeline infrastructure (utilities, transportation) to support community recovery.

*** MICROZONATION:**

the process of dividing a region (often urban areas) into smaller, localized zones with similar hazard levels, based on how different soil and geological conditions amplify shaking during an earthquake. It maps hazards like liquefaction, landslides, and ground motion, directly informing safer, site-specific building codes and land-use planning to reduce risk.

[Harvard.edu: "Seismic Microzonation: A Comprehensive Summary of Principle, Practices and Case Studies of Indian Cities" by Patel, Neelu search by orcid ; Singh, V. P. search by orcid ; Ahamad, Md Naseem; June 2025]

4.3. THE FUTURE OF SEISMIC BUILDING CODES AND THE REGULATORY OVERSIGHT

Regulatory frameworks for seismic design are moving toward functional recovery, riskbased precision, and integration with climateresilience policy. The direction seems to be clearly moving towards codes expecting buildings not just to survive earthquakes, but to remain usable, with design decisions tied to communityscale resilience.

A. **Functional Recovery Will Become a Core Requirement:** The biggest shift is the move from lifesafety to functional recovery, meaning buildings must be safe and usable within a defined time after an earthquake.

- Federal agencies are prioritizing modernization of building codes to improve climate and hazard resilience, including seismic events.70
- This will likely lead to new performance targets for hospitals, schools, housing, and essential facilities.
- Architects and engineers will need to design for limited damage, rapid repair, and continuity of operations.

This is the most transformative regulatory change since the introduction of seismic design categories.

B. **ASCE 7 Will Continue to Move Toward PerformanceBased, RiskTargeted Design:** *ASCE 722* (*Minimum Design Loads and Associated Criteria for Buildings and Other Structures)*, released by the *American Society of Civil Engineers* (ASCE) in late November/early December 2021 has already introduced major updates to

68 mdpi.com; "Earthquake Consideration in Architectural Design: Guidelines for Architects", Sardar S. Shareef, 15 Sept. 2023

69 Architizer.com; "Seismic Safety: Architectural Innovations in Earthquake Zones"; Eric Baldwin;

70 NIBS.org: "Introduction to 2024 Edition Seismic Design Category Maps & FEMA's Building Code Strategy and the National Initiative to Advance Building Codes" by Kelly Cobeen S.E., Wiss Janney Elstner Associates, Jonathan Westcott, P.E., Civil Engineer, Building Science Branch, FEMA-Resilience; 7/11/2024.

seismic provisions, and future editions will deepen this trend. *ASCE 722* includes updated risk categories and "importance" factors that influence seismic design forces.[71]

New load combinations and refined seismic hazard tools are now embedded in design workflows and future editions are expected to expand alternative performancebased pathways, allowing designers to demonstrate acceptable performance through nonlinear analysis rather than prescriptive rules.[72] This means more modeling, more simulation, and more coordination between architects and engineers.

C. **IBC 2024 and Beyond:** Expect more granular Risk Categories and Hazard Mapping.

The 2024 IBC incorporates ASCE 722 and introduces significant structural changes with updates to risk categories in IBC Chapter 16 which reflect a more nuanced understanding of building importance and occupancy.[73] Additionally, FEMA's 2024 seismic design category maps emphasize modernized hazard data and resilience priorities.[74]

Future IBC cycles will likely integrate even more sitespecific hazard modeling, including basin effects and nearfault motions. Architects will need to understand how massing, irregularities, and program distribution affect risk category assignments and seismic demands.

D. **Integration of MultiHazard and ClimateResilience Requirements:** Federal policy is pushing for building codes that address multiple hazards—flood, wind, seismic—under a unified resilience strategy. FEMA highlights modernization of codes as a key national priority for hazard mitigation.[75]

Future seismic provisions will likely integrate with climatedriven requirements such as energy efficiency, sustainability, and extremeevent resilience. This means seismic design will no longer be siloed; it will be part of a broader resilience framework.

E. **Greater Emphasis on Existing Buildings and Retrofit Standards:** ASCE 722 explicitly notes that additions, alterations, and repairs to existing buildings require separate criteria.[76] Future codes are expected to strengthen mandatory retrofit triggers, expand requirements for nonstructural seismic bracing (MEP, façades, ceilings) and also tie retrofit funding to compliance with modern seismic standards. These changes will notably impact renovation and adaptivereuse projects.

F. **More Explicit Requirements for Soil–Structure Interaction and Tsunami Design:** ASCE 722 already includes expanded guidance on soilstructure interaction and tsunami loads.[77] And trends suggest that future codes will likely:

- Require nonlinear SSI modeling for certain building types.
- Expand tsunami design zones and criteria in coastal regions.
- Increase geotechnicalstructural coordination requirements.

This will influence site planning, foundation strategies, and early architectural decisions.

G. **Digital Tools and Hazard Mapping Will Likely Become Mandatory:** The ASCE 7 Hazard Tool is now the standard for retrieving seismic parameters. It provides precise hazard data for seismic, wind, flood, snow, and tsunami risks.[78] In the near future, codes may require digital hazard lookups rather than static maps. This will streamline design but also demand more technical literacy from architects.

These foreseeable changes in both trajectory and substance of regulatory requirements is consistent with an overall tendency of regulators to make codes and guidelines more integrated and have the ability to respond to project and site nuances rather than current prescriptive model that, while reasonably applicable to a broad set of projects and locations, can be problematic or even counter productive in unique circumstances. Hence the move towards a performance-based approach that can be more flexible and therefore meet the public safety welfare requirements more fully as intended for each project, especially those that are functionally multifaceted or must address complex site conditions. As these codes and rules change, enforcement of these will also have to take different arrangements. Building officials and other governing enforcement officials will need to be more technically versed as they will have to understand the performance models presented by designers and be able to challenge these in a meaningful dialog rather than simply enforce the prescriptive dictate of a code. The positive outlook of this potential model is that building designers and regulatory officials can work collaboratively to find the best practical solution while safeguarding public welfare, safety, and building survivability. One potential downside of these emerging trends is that currently codes and regulations provide designers with a shield that limits liability and, in some ways, makes the design process a series of checkboxes and formula compliance. In the new model, liabilities may get redefined and more attention to the design performance will be needed by engineers and architects instead of simply "meeting code".

4.4. SUMMARY & CONCLUSION

This course examined the various natural forces and the geological construct of the Earth that impact building design and focused on those that generate earthquakes. Understanding how earthquakes develop provides the basis for developing an informed response in building design to counter those forces and maintain stability of the building or structure. We also looked at how pre-industrial societies dealt with earthquakes, whether by intuition, observation or trial and error. In the post-industrial era, with greater scientific understanding of the seismic forces, design techniques improved and, while prediction of earthquakes still remains elusive, the ability to withstand and survive the event is greatly improved. At the same time, regulations and codes have evolved to provide guidance and mandate seismic design requirements. We have discussed the many agencies and regulatory bodies that govern seismic design. The 3rd part of the course examined the impacts of seismic design requirements on the practice of Engineering and architecture and how design professionals respond. In the last part, we reviewed the future direction of seismic design and how the nature of codes, regulations and design practice is becoming less prescriptive and more integrated with resilient based design philosophies.

Seismic design, a relatively nascent specialization, is very critical to the regions of the Earth where earthquakes are frequent. Architects and engineers who build in these areas must be alert to the implications

71 STRUCTURE magazine: "2024 IBC Significant Structural Changes Risk Categories (IBC Chapter 16)–Part 5" by John "Buddy" Showalter, P. E., M. ASCE, M. NCSEA, and Sandra Hyde P. E., M. ASCE, M. NCSEA; March 9, 2024.

72 RISA.com: "What's New in ASCE 7-22?"; September16, 2025.

73 See Note 72

74 See Note 71

75 Ibid

76 SEAU.org: "Significant Changes in ASCE 7-22"; by S.K. Gosh Associates; Presentation to SEAU. February 20, 2024.

77 cedEngineering.com: "Overview of the Seismic Design Process Based on ASCE/SEI 7-22"; PDH Course No. S02-039; By Ibrahim M. Metwally, Ph.D, P.E.

78 See Note 77

of seismic forces, a focus that will only become more pronounced in future. With advances in materials, technologies and targeted design approaches, seismic design continues to advance, albeit with greater complexity. With a paradigm shift that extends seismic design beyond earthquake resistance and collapse prevention to a more resilient approach where buildings will be expected to not only survive an earthquake but remain effectively functional in the aftermath. These approaches bode well for the public and while they place more responsibilities on architects and engineers, they are likely to yield more rewards for everyone.

END PART 4

PART 4 REVIEW QUESTIONS

1. **Which of the following are true statements?**
   - A. Buildings are moving toward continuous, real time seismic awareness
   - B. Material science is accelerating seismic innovation
   - C. A & B
   - D. Building codes are becoming more prescriptive

2. **Seismic cloaking is _____?**
   - A. Combining elastomeric bearings with sliding mechanisms
   - B. Redirecting seismic waves around structures
   - C. When S and P waves overlap
   - D. A shift in building structure that appears seismic but is not

3. **Future focus of seismic design is likely to…?**
   - A. Expand from "designing for forces" to designing for resilience, recovery, and lifecycle performance
   - B. Develop highly prescriptive codes
   - C. Replace Resilient design trends
   - D. Be limited to California and the Pacific states

4. **For architects, next-generation seismic systems could mean…?**
   - A. Greater freedom to explore expressive forms because advanced damping and isolation can manage irregularities
   - B. Totally AI generated buildings with no need for human interaction
   - C. Government mandated pre-determined design templates
   - D. B & C

5. **Which of the following is/are true statements?**
   - A. Seismic design is now able to predict earthquakes up to 72 hours in advance
   - B. Sustainability and seismic resilience are converging
   - C. Functional recovery will likely become a core requirement of seismic design
   - D. B & C

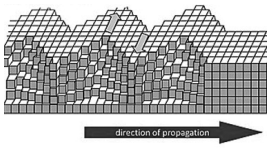
REVIEW QUESTION ANSWERS

Part 1 Review Questions

1. **Which layer of the earth is the portion where earthquakes are felt?**
   - *A. Mantle; Incorrect.*
   - *B. Core; Incorrect.*
   - **C. Lithosphere; Correct. The rigid outermost shell is referred to as the lithosphere, this is the layer humans and most life on earth lives and where earthquakes are felt.**
   - *D. Stratosphere; Incorrect*

2. **The location below the earth's surface where the earthquake starts is called the _____.**
   - *A. Fault plane; Incorrect.*
   - **B. Hypocenter; Correct. The location below the earth's surface where the earthquake starts is called the hypocenter, and the location directly above it on the surface of the earth is called the epicenter.**
   - *C. Epicenter; Incorrect.*
   - *D. Crust; Incorrect.*

3. **This illustration depicts what kind of seismic wave?**



   - *A. W wave; Incorrect.*
   - *B. S wave; Incorrect.*
   - **C. Love wave; Correct. In the image of Seismic Waves, this wave illustration depicts a Love Wave.**
   - *D. Rayleigh wave; Incorrect.*

4. **An earthquake of intensity "V" on the MMI scale would be classified as:**
   - *A. Violent; Incorrect.*
   - *B. Weak; Incorrect.*
   - *C. Severe; Incorrect.*
   - **D. Moderate; Correct. According to the figure showing the MMI scale, an intensity of "V" is a "Moderate" earthquake.**

5. **Which of the following building characteristics are better for seismic design?**
   - **A. Flexible steel frames; Correct. Steel frames and wood-frame structures often offer better flexibility and resilience.**
   - *B. Unreinforced masonry; Incorrect.*
   - *C. Irregular shape; Incorrect.*
   - *D. All of the above; Incorrect*

Part 2 Review Questions

1. **The first U.S. state to adopt a seismic code was:**
   - *A. Oregon; Incorrect.*
   - *B. Colorado; Incorrect.*
   - **C. California; Correct. In response to the 1933 Long Beach earthquake, California became the first US state to mandate statewide minimum structural standards.**
   - *D. Alaska; Incorrect.*

2. **The most significant standard for seismic design related to buildings is _____?**
   - **A. ASCE 7; Correct. For building design, perhaps the most important standard is the ASCE 7, which forms the backbone of seismic design for buildings in the US and is widely used in other parts of the world.**
   - *B. IBC Chapter 7; Incorrect.*
   - *C. BOCA 1943; Incorrect.*
   - *D. UN Building Council Sec. 33-2; Incorrect.*

3. **What is the popular name for the Circum-Pacific belt seismic zone?**
   - *A. Sino-American Plate; Incorrect.*
   - **B. Ring of Fire; Correct. Know as the "Ring of Fire", also called the Circum-Pacific belt, is the zone of earthquakes surrounding the Pacific Ocean.**
   - *C. Trans Andean Zone; Incorrect.*
   - *D. Middle America trench; Incorrect.*

4. **How does the IBC guide seismic building design?**
   - *A. Defers to states; Incorrect.*
   - *B. Use of hazard classifications; Incorrect.*
   - *C. Use of seismic Zones; Incorrect.*
   - **D. Use of seismic design categories (SDCs); Correct. For applications related to building design, the IBC uses seismic design categories (SDCs, A-F) that come from ASCE 7.**

5. **A building in SUG II would be classified as what type of occupancy?**
   - *A. Standard occupancy; Incorrect.*
   - *B. Non-combustible; Incorrect.*
   - **C. Essential facility; Correct. Buildings in SUG II are Essential Facilities.**
   - *D. Critical occupancy; Incorrect.*

Part 3 Review Questions

1. **In pre-industrial times seismic design was:**
   - *A. Ignored; Incorrect.*
   - **B. Based on observations, trial and error and pattern recognition; Correct. Pre-industrial societies tried to predict earthquakes in a variety of ways, including observations, trial and error, and pattern recognition.**
   - *C. Based on scientific calculations; Incorrect.*
   - *D. Developed using plate tectonic theory; Incorrect.*

2. **Which of the following is a characteristic of why Gutenberg Castle in Lichtenstein and similar medieval structures have survived seismic events?**
   - *A. Flexible timber frames; Incorrect.*
   - *B. Inclined turrets; Incorrect.*
   - **C. Dense masonry with excellent mass distribution; Correct. The Gutenberg Castle has survived due to dense stone masonry with excellent mass distribution, elevated bedrock foundation, and structural continuity that resists shear failure.**
   - *D. Polygonal stones with precision cuts*

3. **A foundational theory of modern earthquake science is _____?**
   - *A. Zonal relativity theory; Incorrect.*
   - **B. Elastic rebound theory; Correct. The 1906 San Francisco Earthquake led to the development of the elastic rebound theory, forming the foundation of modern earthquake science.**
   - *C. Seismic Uplift theory; Incorrect.*
   - *D. None of the above; Incorrect.*

4. **Which chapter of the IBC requires special inspection and testing for seismic structures?**
   - *A. 12; Incorrect.*
   - *B. 32; Incorrect.*
   - *C. 21; Incorrect.*
   - **D. 17; Correct. Special inspections and testing to ensure seismic detailing is built correctly is required by IBC Chapter 17.**

5. **Which of the following is not a consideration for seismic architecture?**
   - **A. Building color; Correct. For seismic architecture, main considerations include drift compatibility, façade and cladding anchorage, doors and windows, etc. Building color is not a listed consideration.**
   - *B. Doors and windows; Incorrect.*
   - *C. Façade and Cladding Anchorage; Incorrect.*
   - *D. Drift Compatibility; Incorrect.*

Part 4 Review Questions

1. **Which of the following are true statements?**
   - *A. Buildings are moving toward continuous, real time seismic awareness; Incorrect.*
   - *B. Material science is accelerating seismic innovation; Incorrect.*
   - **C. A & B; Correct. As described in section 4.1, buildings are moving towards continuous, real time seismic awareness and material science is accelerating seismic innovation.**
   - *D. Building codes are becoming more prescriptive; Incorrect.*

2. **Seismic cloaking is _____?**
   - *A. Combining elastomeric bearings with sliding mechanisms; Incorrect.*
   - **B. Redirecting seismic waves around structures; Correct. Seismic cloaking concepts aim to redirect seismic waves around structures.**
   - *C. When S and P waves overlap; Incorrect.*
   - *D. A shift in building structure that appears seismic but is not; Incorrect.*

3. **Future focus of seismic design is likely to…?**
   - **A. Expand from "designing for forces" to designing for resilience, recovery, and lifecycle performance; Correct. The role of seismic design is expanding from "designing for forces" to designing for resilience, recovery, and lifecycle performance.**
   - *B. Develop highly prescriptive codes; Incorrect.*
   - *C. Replace Resilient design trends; Incorrect.*
   - *D. Be limited to California and the Pacific states; Incorrect.*

4. **For architects, next-generation seismic systems could mean…?**
   - **A. Greater freedom to explore expressive forms because advanced damping and isolation can manage irregularities; Correct. For architects, next-generation seismic systems means greater freedom to explore expressive forms because advanced damping and isolation can manage irregularities.**
   - *B. Totally AI generated buildings with no need for human interaction; Incorrect.*
   - *C. Government mandated pre-determined design templates; Incorrect.*
   - *D. B & C; Incorrect.*

5. **Which of the following is/are true statements?**
   - *A. Seismic design is now able to predict earthquakes up to 72 hours in advance; Incorrect.*
   - *B. Sustainability and seismic resilience are converging; Incorrect.*
   - *C. Functional recovery will likely become a core requirement of seismic design; Incorrect.*
   - **D. B & C; Correct. According to the course, sustainability and seismic resilience are converging, and functional recovery will become a core requirement of seismic design.**

Notes

Notes

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BIOMIMICRY AND REGENERATIVE DESIGN

Course # AIAPDH275
4 LU | HSW Hours

BIOMIMICRY AND REGENERATIVE DESIGN
FINAL EXAM (25 QUESTIONS)

1. **What is Biophilic Design?**
   A. Design that focuses on ignoring human well-being by incorporating toxic elements that harm the natural environment.
   B. Design that focuses on improving human well-being by incorporating natural elements into the built environment.
   C. Design that focuses on decreasing human well-being by incorporating unnatural elements into the built environment.
   D. Design that focuses on the psychological destruction of human well-being by incorporating deadly elements into the built environment.

2. **What is Biomimicry?**
   A. Using systems found in nature to design more efficient and sustainably built environments.
   B. Using systems found in nature to design more inefficient and unsustainable built environments.
   C. Using systems found in space to design inefficient and unsustainable built environments.
   D. Using systems found in the earth's core to design more inefficient and toxic built environments.

3. **Which is an example of implementing Biophilic Design?**
   A. Designing an interior space with no windows.
   B. Incorporating indoor plants and natural wood into a main lobby.
   C. Designing an interior one-story lobby with artificial daylighting only.
   D. Incorporating a faux skylight in an interior lobby with no daylight.

4. **Which is an example of Biomimicry?**
   A. Designing a building with design elements modeled after a pinecone or termite mound.
   B. Designing a standard HVAC system.
   C. Incorporating indoor plants and natural wood into a main lobby.
   D. Incorporating earth color toned finishes into the design.

5. **What is the 3rd step of the 4-Step Biomimicry Thinking Flowchart that AEC professionals can use?**
   Step 1: Define the Challenge
   Step 2: Emulate Nature's Strategies
   Step 3: _____
   Step 4: Evaluate and Refine
   A. Contact a Biomimicry specialist
   B. Apply the Strategy
   C. Repeat Steps 1 & 2
   D. There is no Step 3

6. **What is the 4th principle of the 6 Biomimicry Life's Principles?**
   1) Evolve to Survive 2) Adapt to Changing Conditions 3) Be locally attuned and Responsive 4) _____ 5) Be Resource Efficient 6) Integrate Development with Growth
   A. Use toxic chemicals sparingly
   B. Use life-friendly chemistry
   C. Destroy all natural life
   D. Development supersedes natural habitats

7. **What are the Biomimicry Life's Principles?**
   A. There are 6 principles
   B. Design lessons from nature
   C. Design lessons from Brutalism inspired architecture
   D. Design principles that focus on the earth tone colors

8. **How many Biomimicry Life Principles were there originally?**
   A. 15
   B. 11
   C. 9
   D. 300

9. **Who are the co-founders of Biomimicry?**
   A. Oprah Winfrey and Henrietta Lacks
   B. Alma Levant Hayden and Beth A. Brown
   C. Janine Benyus and Dr. Dayna Baumeister
   D. Patrick Mahomes and Travis Kelce

10. **What is available to AEC firms and practitioners to show a deeper understanding of Biomimicry?**
    A. Nothing exists to date
    B. Toxic Chemical Use certification
    C. Certified Biomimicry Professional Program
    D. International Housefire Code

11. **What is Wolff's Law?**
    A. The idea that natural healthy bones will not adapt and not change to adapt to the stress that it is subjected to.
    B. The idea that natural healthy skin will adapt and change to adapt to the stress that it is subjected to.
    C. The idea that natural healthy bones will adapt and change to adapt to the stress that it is subjected to.
    D. The idea that when the body breaks down old bone faster than it can create new bone.

12. What are diatoms used in?

A. Batt insulation
B. Ultra-high-performance concrete (UHPC)
C. Treated 2x wood
D. Spray foam

13. Where was the first UHPC bridge located?

A. USA
B. Africa
C. Canada
D. South America

14. What do Frank Lloyd Wright's columns in the Johnson Wax Building resemble?

A. Tree Trunks and Branches
B. Ripples of the Water
C. Rays of the Sun
D. Grains of Sand

15. Where was the world's first 3D-printed stainless-steel bridge located?

A. USA
B. South Korea
C. The Netherlands
D. Namibia

16. Which is NOT the AEC Translations(s) for a Lotus Leaf and its ability to remain spotless?

A. Self-Cleaning Facades
B. Water-Repellant Membranes
C. Windshield Wipers on a Car
D. Self-Cleaning Roofs

17. Regarding Mangrove trees, what principle(s) do they embody?

A. Quality sound absorption
B. Filtration of saltwater through specialized root structures
C. Colorful root system
D. Low Reverberation

18. Which fruit possesses principle(s) that would work well in a dry-arid climate?

A. Pineapple
B. Apple
C. Plum
D. Kiwi

19. What animal produces silk that showcases the principle(s) of tensile strength?

A. Moth
B. Spider
C. Black Panther
D. Cheetah

20. Which existing building condenses atmospheric moisture similar to the Namib Desert Bettle for storage and distribution to rural areas?

A. Tuskegee University Chapel
B. Terminal One at LAX
C. Warka Water Towers
D. Unity Funeral Home

21. What is a Mashrabiya screen?

A. Proprietary guardrail
B. Intricate, latticed wooden screens common in African architecture
C. Intricate, latticed wooden screens common in European architecture
D. Intricate handrail system

22. What makes Khoo Teck Puat Hospital unique from a Biomimicry standpoint?

A. Designed to be locally attuned and responsive to its surrounding environment
B. Built in Singapore
C. Branding logo
D. Designed to be shaped like an acorn

23. What natural model did Eastgate Centre follow?

A. Shark Fins
B. Termite Mounds
C. Mollusk Shells
D. Octopus

24. The Harbin Opera House insulation system mimics what animal or natural model?

A. Penguin Feathers
B. Turkey Legs
C. The eye of a newt
D. Grasshopper

25. What would the AEC Translations(s) be for an Abalone shell?

A. Blast-resistant panels
B. Plate Glass
C. EIFS/Stucco
D. Washi Tape

END OF FINAL EXAM

BIOMIMICRY AND REGENERATIVE DESIGN

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Course Summary

This 4-hour LU/HSW course introduces AEC professionals to biomimicry as a nature-inspired design methodology, using real-world examples to show how natural strategies can be applied to create regenerative, high-performance buildings that enhance sustainability, resilience, and overall occupant well-being.

Learning Objectives

1. **Differentiate** the human-centric goals of Biophilic Design from the technical process of Biomimicry and Apply the Biomimicry Thinking methodology to multiple AEC-related exercises.
2. **Identify** existing natural systems that are being developed into advanced solutions for structural optimization and passive climate control.
3. **Identify** existing natural systems that are being developed into advanced solutions for water management and material surface science.
4. **Identify** and Understand buildings with integrated biomimetic strategy and regenerative performance.

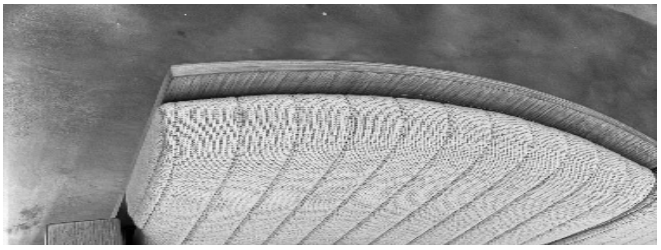
Course Structure

- ✓ **PART 1 –** The Foundations: From Biophilic Goals to Biomimicry and its History
- ✓ **PART 2 –** Biomimicry in Structure and Thermal Systems
- ✓ **PART 3 –** Biomimicry in Water Management and Material Surface Science
- ✓ **PART 4 –** Real World Examples of Integrated Biomimetic Strategy and Regenerative Performance in the Built Environment

BIOMIMICRY AND REGENERATIVE DESIGN COURSE

PART 1 – THE FOUNDATIONS: FROM BIOPHILIC GOALS TO BIOMIMICRY AND ITS HISTORY

Learning Objective No. 1: Differentiate the human-centric goals of Biophilic Design from the technical process of Biomimicry and A*pply the Biomimicry Thinking methodology to multiple AEC-related exercises.*



Before we get started let's differentiate between biophilic design and biomimicry.

Biophilic design *improves the building for the occupants*

and

Biomimicry improves the performance of the building in relation to the environment and indirectly also for the occupants. Let's investigate both in more detail and specificity.



Figure 1.1. – Example of Biophilic Design. © Scott Webb, Pexels.com

Biophilic Design:

Biophilic Design focuses on improving human well-being by incorporating natural elements, patterns, and experiences into the built environment.

Biomimicry:

Biomimicry uses nature's systems, structures, and strategies as technical models to design more efficient, sustainable, and high-performing solutions for the built environment.

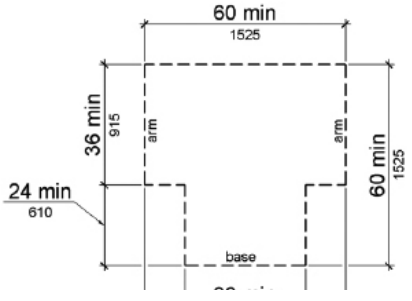


Figure 1.2. – Example of Biomimicry. © Rick Otten, Pexels.com

The differences between both can be found below:

Differences between Biophilic Design and Biomimicry

BIOPHILIC DESIGN	BIOMIMICRY
Human-centric approach focused on improving occupant (human or animal) health, well-being, and emotional connection to nature.	Technical, problem-solving approach focused on copying or mimicking nature's strategies to improve performance, efficiency, or structure typically within the built environment.
Enhances comfort, mood, productivity, and stress reduction through natural elements.	Enhances function, performance, durability, and sustainability of buildings, et. cetera by emulating biological systems.
Uses nature for an experience (sunlight, plants, natural materials, views, water).	Uses nature for solutions (structural forms, materials, energy systems, airflow patterns).
Aims to create spaces where humans feel at peace and function better.	Aims to create products, buildings, or systems that work better by mimicking nature's mechanisms that have withstood the test of time.
Focuses on sensory and psychological benefits — color, texture, pattern, smell, touch, views, sounds.	Focuses on mechanical, structural, and environmental optimization, strength, self-cleaning, cooling, efficiency.
Involves design choices like incorporating natural light, greenery, organic shapes, and natural materials into a space.	Involves studying nature and applying scientific principles, like termite mounds for ventilation or lotus leaves for self-cleaning surfaces.
Concerned with how people feel inside a space. Mental health.	Concerned with how a building or system performs or behaves.
Mainly used by architects, interior designers, and planners.	Used by architects, engineers, product designers, and material scientists.
Goal: Human wellness + emotional connection to nature.	Goal: Technical innovation + efficiency inspired and then guided by nature.
Example: Adding indoor plants, natural wood wall paneling or flooring, water features, and daylighting.	Example: Designing a façade modeled after a pinecone, or an HVAC system modeled after termite mound cooling.

Biophilic Design:

Biophilic design focuses on creating environments that connect building occupants with nature, promoting well-being, healthy surroundings, creativity, serenity, and productivity.



Figure 1.3. – Biophilic design promotes peace. © Yan Krukau, Pexels.com

It's centered on improving the *quality of life* for occupants through natural elements and patterns. Through the lens of architecture, this means your end-user feeling at peace and calm in a very high pressure and high stress environment or at the very least having a space to retreat to, to re-center their thoughts.

Key Biophilic Design Goals:

1. **Psychological Well-being:** Improve the mental and emotional health of building occupants through nature-inspired designs, which lends itself to a reduction in stress.
2. **Connection to Nature:** Foster a sense of direct or indirect connection to natural elements (i.e. plants, water features, natural light, wind). Through the lenses of architecture this can be achieved by incorporating interior gardens, ivy on exterior walls, fountains, access to an abundance of natural light, et. cetera into the design.
3. **Enhanced Productivity:** Design environments that improve cognitive function, nurture and increase creativity, and reduce stress and increase mindfulness.
4. **Aesthetic Engagement:** Integrate natural forms (*think Zaha Hadid and the use of curves, as there are no truly straight lines in nature*), colors, and textures to create visually stimulating and calming spaces.
5. **Biodiversity:** Encourage a seamless and harmonious relationship between natural and built environments, enhancing ecosystem services. A really great example of this is SoFi stadium in California.

"...When it came to academic results, the students in the biophilic classroom experienced 3.3x the average test score gain compared to the control students. At the end of the seven-month study, 7.2% more students in the biophilic classroom tested at grade level than control students..." – Spaces4Learning

THE HISTORY OF BIOMIMICRY

Timeline

- **1997 –** The origin of Biomimicry and its life's principles was the culmination of twenty plus years of work by biologists, biomimics, and designers.
- **1998 –** Janine Benyus and Dr. Dayna Baumeister co-founded the Biomimicry Guild as an innovation consultancy.
- **2006 –** Janine Benyus co-founded The Biomimicry Institute with Dr. Dayna Baumeister and Bryony Schwan
- **2008 –** Biomimicry Institute launched AskNature.org, "an encyclopedia of nature's solutions to common design problems"
- **2010 –** Biomimicry 3.8 is formed and offers consultancy, professional training, development for educators, and "inspirational speaking"

Co-Founders of the Biomimicry Movement

Janine Benyus

Authored *Biomimicry: Innovation Inspired by Nature (1997),* which developed the following thesis that human beings should consciously emulate nature's genius in their designs. She encourages people to ask, ***"What would Nature do?"*** and to look at natural forms, processes, and ecosystems in nature to see what works and what lasts

- Coined the term "Biomimicry" to describe intentional problem-solving design inspired by nature
- President of Living Education, a nonprofit dedicated to place-based living and learning



Figure 1.3.1. – Janine Benyus © Heinzawards.org

"After 3.8 billion years of research and development, failures are fossils, and what surrounds us is the secret to our survival."
– Janine M. Benyus

Dr. Dayna Baumeister

- Designed (and continues to teach) the world's first Certified Biomimicry Professional Program, an in-person, 2-year master level course that trains, certifies, and connects biomimicry professionals with practitioners world-wide
- Co-designed the Biomimicry Specialist Program
- Senior editor of Biomimicry Resource Handbook: A Seed Bank of Knowledge and Best Practices (2014)



Figure 1.3.2. – Dr. Dayna Baumeister © sustainabilityleadersnetwork.org

Originally there were 9 principles, which were described in "*Biomimicry: Innovation Inspired by Nature*".

The original 9 principles are listed below:

Original 9 Principles

1. Nature runs on sunlight
2. Nature uses only the energy it needs
3. Nature fits form to function
4. Nature recycles everything
5. Nature rewards cooperation
6. Nature banks on diversity
7. Nature demands local expertise
8. Nature curbs excesses from within
9. Nature taps the power of limits



Figure 1.3.3. – "When the sun rises, the sunflower follows it loyally. Learn from the sunflower how to be true to your path." – Lakota Proverb © Vitaliy Bratkov , Pexels.com

Current 27 Principles

The current Biomimicry Life's Principles are a set of 27 strategies that all organisms and ecosystems on Earth use for creating conditions conducive to life. The strategies are also beneficial to any organization or design.

1. Evolve To Survive A. Replicate Strategies that Work B. Integrate the Unexpected C. Reshuffle Information **2. Be Locally Attuned and Responsive** A. Leverage Cyclic Processes B. Use Readily Available Materials and Energy C. Use Feedback Loops D. Cultivate Cooperative Relationships **3. Be Resourceful with Material and Energy** A. Use Low Energy Processes B. Use Multi-Functional Design C. Recycle All Materials D. Fit Form to Function	**4. Adapt To Changing Conditions** A. Incorporate Diversity B. Maintain Integrity through Self-Renewal C. Embody Resilience **5. Integrate Development with Growth** A. Self Organize B. Build from the Bottom Up C. Combine Modular and Nested Components **6. Use Life-friendly Chemistry** A. Employ Elegant Processes B. Use a Small Subset of Elements C. Do Chemistry in and with Water D. Break Down Products into Benign and Useful Constituents

The 6 Overarching Biomimicry Life's Principles

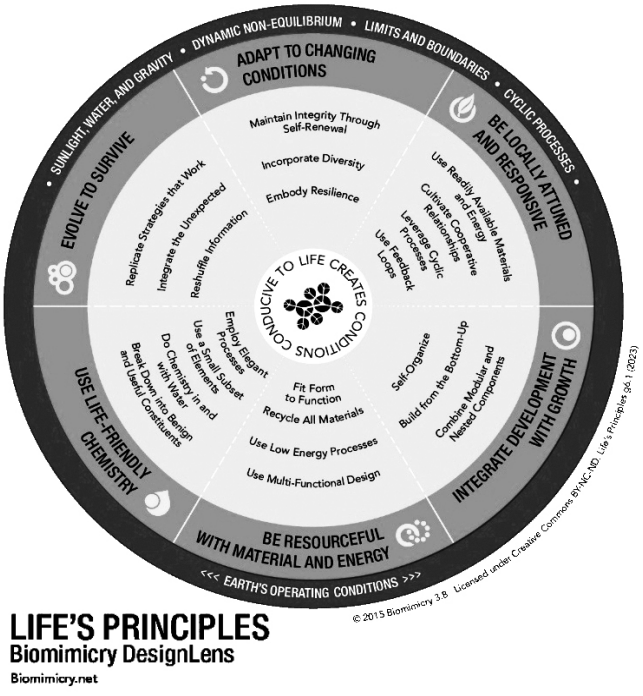


Figure 1.3.4. – 6 Life's Principles © biomimicry.net

1. **Evolve to Survive**
2. **Adapt to Changing Conditions**
3. **Be locally attuned and Responsive**
4. **Use Life-friendly Chemistry**
5. **Be Resourceful with Material and Energy**
6. **Integrate Development with Growth**

Biomimicry Methods:

Biomimicry borrows its inspiration and direction from nature's patterns, processes, and strategies in order to solve human design and built environment challenges. Biomimicry looks to nature for innovative, time-tested and lasting solutions to enhance efficiency, sustainability, and resilience in the built environment. The irony is not lost on us that we create the built environment to mimic nature when we could just exist within nature and not create a built environment – problem solved without ever creating the problem.

Key Biomimicry Methods:

1. **Learning from Nature's Designs**: Identifying natural systems and processes that can be applied to human challenges (i.e. self-healing materials inspired by biological cells).
2. **Circular or Closed-Loop Systems**: Designing circular or closed-loop systems, paralleling nature's ability to recycle waste, reduce energy consumption, and use materials efficiently.
3. **Adaptation and Resilience**: Studying how organisms adapt to their environments and using those same or similar methods to improve the built environment, for example building resilient buildings in response to climate change.
4. **Energy Efficiency**: Paralleling nature's strategies for energy exchange, such as passive cooling or solar energy capture methods, which can be applied in buildings.
5. **Efficient Use of Resources**: Using minimal resources to create highly efficient systems, akin to how certain plants or animals use minimal energy for maximum output.

"Jellyfish may be the most energy-efficient animals in the world"
– Gizmodo

BIOMIMICRY 4 STEP PROCESS THROUGH THE LENS OF AEC



Figure 1.3.5. – Bahia, Brasil, South America © Priscila Almeida, Pexels.com

The following 4 step process is designed to smoothly transition or convert any building design challenge into a nature-based solution. The following process has been geared towards AEC professionals:

Step 1: Define the Challenge

- **Goal**: Clearly articulate the design or operational challenge. Consider the site, local materials, and the macro and microclimates.
- **Example**: How can we design a building in the semi-arid tropical climate ("BSh" per the Köppen Climate Classification System) of Caatinga, Rafael Jambeiro Municipality, Bahia (BA), Brasil, South America that reduces energy consumption and improves indoor air quality (IAQ)?

Key Question To Ask Yourself/Team: What specific problem are we solving? (i.e. energy inefficiency, poor indoor air quality, et. cetera)

Step 2: Emulate Nature's Strategies

- **Goal**: Search locally within the microclimate and then expand to the macroclimate first to learn how native elements of nature, animals, etc. survive and thrive in the climate of that local area and region. Then identify natural models, processes, or behaviors that address the design or operational challenge.
- **Example**: Look at termite mounds for natural ventilation, study how fish use hydrodynamics for energy-efficient movement in water, or how cactus adapt to arid environments for water conservation.

Key Question: Locally, what natural systems, organisms, or processes can provide inspiration? How does nature solve similar problems, more specifically the design challenge?



Figure 1.4. – Nature has all the answers.
© Chevanon Photography, Pexels.com

Step 3: Apply the Strategy

- **Goal**: Translate nature's strategy into a usable, practical design solution for the built environment.
- **Example**: Use biomimetic principles to create a passive cooling system based on termite mound ventilation, apply bio-inspired shading devices to reduce solar heat gain, or develop a water harvesting system based on cactus-like structures.

Key Question: How can we adapt this biological principle or system for use in our built environment? How does it integrate with existing and upcoming construction technologies?

Step 4: Evaluate and Refine

- **Goal**: Evaluate the impact and effectiveness of the biomimetic solution.
- **Step 4 Example**: Test how the proposed solution (i.e., natural ventilation, energy-saving design) performs in a real-world setting and refine it based on feedback, environmental conditions, and performance metrics. The findings can be used to improve the next similar building design challenge.

Key Question: Does the solution achieve the desired outcomes in terms of sustainability, performance, and user experience? What improvements can be made for the project or future projects?

BIOMIMICRY FLOWCHART (NATURE TO BUILT ENVIRONMENT)

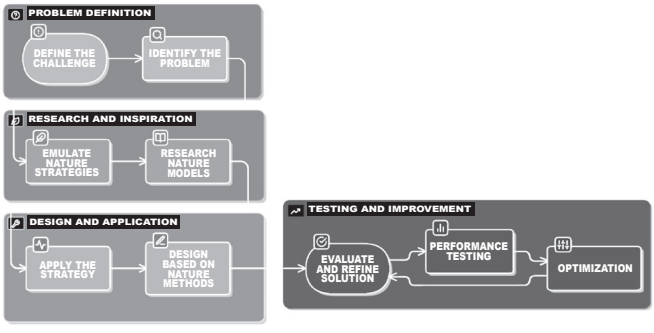


Figure 1.5. – Visual of the Biomimicry Flowchart (Nature to Built Environment)

Key Benefits for AEC Professionals:

1. **Sustainability**: Using nature's inherent efficiency to reduce waste, energy consumption, and material usage.
2. **Resilience**: Designing with nature's proven strategies *(remember the co-founder of Biomimicry's quote above)* to increase the durability and adaptability of buildings.
3. **Innovation**: Stimulating new ideas for problem-solving by looking beyond conventional solutions to nature's time-tested systems.
4. **Cost-Effectiveness**: Reducing long-term operational costs through efficient energy use, water management, and waste reduction.

Great resources when searching for Nature-Based Solutions:

WEBSITES	*DESCRIPTION*
https://biomimicry.org/	**Biomimicry Institute** The Biomimicry Institute is a leader in biomimicry research. Within is a wealth of resources on how nature can inspire innovative design solutions. The Biomimicry 3.8 program offers case studies, design tools, and educational materials to help individuals and organizations learn about nature-inspired innovation.
https://asknature.org/	**AskNature** An interactive database for biomimetic innovations that gives access to thousands of nature-inspired design solutions across various industries like architecture, energy, and materials.
https://www.learnbiomimicry.com/	**Biomimicry** They work with biomimicry practitioners, influential educators, and accomplished professionals to bring forth Nature's winning strategies.

APPLYING BIOMIMICRY THINKING TO COMMON PROBLEMS OR CHALLENGES IN THE AEC INDUSTRY

Common Problem Exercise 1: Overheating of the Western façade of a structure

1. Define the Challenge (What is the problem?)

Challenge: The overheating of the western façade of a building.

Desired Outcome: The western façade must reduce heat gain, block harsh low angle afternoon sun, and maintain daylight without relying heavily on active or mechanical cooling systems.

2. Emulate Nature's Strategies (How does nature solve this?)

Research and search for organisms and elements of nature that face a similar situation (intense afternoon heat) and have strategies for rejecting, reflecting, shading, or dispersing said heat. Refer to the following examples:

- **Pinecones** that open/close depending on environmental conditions.
- **Saguaro cactus ribs** that cast self-shade throughout the day.
- **Termite mounds** that regulate internal temperature with passive ventilation.
- **Desert beetles** with reflective shell surfaces that reduce solar absorption.
- **Leaf canopies** that create layered shading without blocking wind or light.



Figure 1.6. – Nature teaches if you listen. © Nathalie De Boever, Pexels.com

3. Apply the Strategy i.e. Biology to Design (Translating biological strategies into building concepts)

Based on the organisms above, generate design solutions inspired by the mechanisms listed in Step 2:

- **From pinecones:** Design thermal-responsive shading panels that open/close based on heat or sun intensity.
- **From cactus ribs:** Design vertical or faceted fins that create self-shading on the west façade as the sun moves.
- **From desert beetle shells:** Use reflective or high-albedo façade surfaces that reject a significant portion of solar radiation.
- **From termite mound ventilation:** Incorporate passive ventilation channels or stack cooling cavities behind the façade to dissipate heat.
- **From leaf canopies:** Create layered shading screens (perforated metal, louvers, or lattice systems) that reduce direct solar gain but still allow daylight and airflow.

4. Evaluate & Refine (Does the nature-inspired solution work? How does it perform?)

Test concepts through simulations and prototypes:

- Solar studies to measure heat reduction
- Daylighting analysis to avoid over-darkening
- Wind/airflow modeling for passive cooling performance
- Constructability and cost assessments

5. Integration (Scale into a real building solution)

Combine the most effective biological strategies into a cohesive façade system, for example:

A western facing façade with angled cactus-like fins paired with reflective coatings (mimicking the desert-beetle) which creates passive airflow channels, creating a highly efficient biomimetic envelope that cools itself naturally.

In Summary

By studying how nature and its creatures reflect, shade, or ventilate against intense afternoon heat along the Western facade, it is possible to find a solution using the following:

- self-shading through thermal-responsivity (cactus)
- reflectivity (desert beetle)
- and passive ventilation (termites)

all of which dramatically reduces heat gain in the interior space of a structure placed along the Western facade.

Common Problem Exercise 2: Heat Island Effect



Figure 1.7. – Heat Island Effect Can Increase Energy Costs up to 30%.
© Dar ius, Pexels.com

1. Define the Challenge (What is the problem?)

To reduce energy costs and energy consumption along with associated emissions, illness and death due to heat island effect (some areas experience temperature increases of up to 15-20 degrees Fahrenheit versus vegetated areas).

> **"Numerous studies have linked extreme heat with illness and death among vulnerable populations such as older adults, very young children, and people with respiratory illnesses. Extreme heat can also damage essential services such as transportation and energy systems and reduce productivity." – RFF.org**

The goal is to reduce ambient temperatures in urban areas, cool surfaces, increase shade, and improve airflow to make the city more comfortable and energy efficient.

2. Emulate Nature's Strategies (How does nature solve this?)

Research and find in nature, organisms or ecosystems that stay cool in hot environments or manage heat efficiently, such as:

- **Termite mounds** – maintain stable internal temperatures despite extreme heat outside.
- **Mangrove Forests** – reduce surface heat through shade and water evaporation. *(Refer to Figure 1.8 below)*
- **Lotus leaves** – repel heat and water through reflective surfaces.
- **Desert plants (succulents, cacti)** – store water and reduce surface heat through reflective textures and orientation.
- **Urban trees and forest canopies** – provide shade and facilitate evaporative cooling.

3. Apply the Strategy i.e. Biology to Design (Translating biological strategies into building concepts)

From termite mounds:

Incorporate into the design ventilation corridors (learn about Stuttgart's ventilation corridors in Germany), open courtyards, and building layouts to promote airflow and dissipate heat.

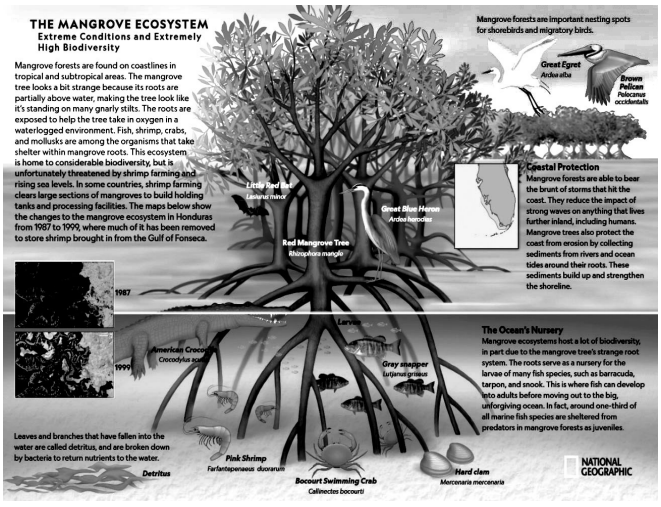


Figure 1.8. – The Mangrove Ecosystem.
© National Geographic, https://education.nationalgeographic.org/resource/the-mangrove-ecosystem/

From mangrove forests:

- Introduce water features such as fountains, and wetlands that cool surrounding areas through evaporation.

From lotus leaves:

- Utilize high-albedo surfaces (i.e. a surface that strongly reflects sunlight and has low absorption), this can be placing reflective materials on roofs, pavements, and facades to reflect solar radiation.

> **"…To determine the ideal implementation of cool pavements in Boston and Phoenix, researchers investigated the life cycle impacts of shifting from conventional asphalt pavements to three cool pavement options: reflective asphalt, concrete, and reflective concrete…" – MIT.edu**

From desert plants:

- Implementation of green roofs, vertical gardens, and shading elements to store less heat and reduce surface temperature.

From urban trees/forests:

- Expand street trees, green corridors, and parks to provide shade and promote evapotranspiration cooling. This contributes to the "ventilation corridors" mentioned above.

4. Evaluate & Prototype (Test the strategies)

- Model urban heat reduction using thermal simulations.
- Measure shade coverage, airflow patterns, and reflective efficiency.
- Test combinations of green infrastructure, reflective materials, and water features for maximum cooling impact.

5. Evaluate & Refine (Does the nature-inspired solution work? How does it perform?)

Combine strategies for a holistic Urban Heat Island (UHI) mitigation approach:

- Tree-lined streets + green roofs + reflective pavements + water features + optimized building orientation. This mimics how nature manages heat while creating healthier, cooler urban environments.



Figure 1.9. – Mangrove forest in its natural habitat.
© Ksu&Eli Studio, Pexels.com

SUMMARY

By mimicking nature's strategies—trees for shade, lotus leaves for reflectivity, mangroves for evaporative cooling, and termite-inspired airflow—cities can reduce the heat island effect and create cooler, more comfortable urban environments.

COMMON PROBLEM EXERCISE 3 (FOR ENGINEERS): OPTIMIZATION OF STRUCTURAL SYSTEMS UNDER EXTREME HEAT LOADS

1. Define the Challenge (What is the problem?)

Structural systems as it pertains to structural stress, increased energy demand and overheating. The desired outcome being to reduce structural stress and maintain durability while minimizing energy demand and overheating in buildings.

2. Emulate Nature's Strategies (How does nature solve this?)

- **Termite mounds:** Maintain stable internal temperatures despite extreme external heat.
- **Cactus ribs:** Shade and self-cool surfaces naturally.
- **Desert lizards:** Use reflective and light-colored skin to reduce heat absorption.

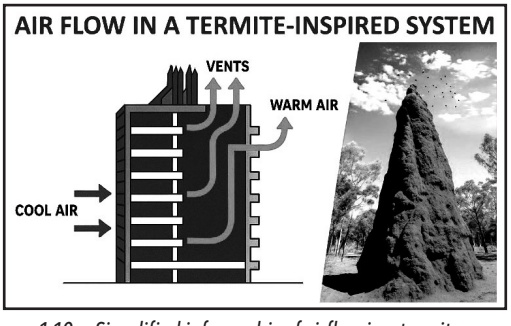


Figure 1.10. – Simplified infographic of airflow in a termite mound.
© sustainabilityglobal.org

3. Apply the Strategy i.e. Biology to Design (Translating biological strategies into building concepts)

- Integrate passive ventilation channels inspired by termite mounds into structural cavities.
- Design facade fins or structural shading elements inspired by cactus ribs.
- Use lightweight, reflective cladding modeled after desert lizard reflective skin.

4. Evaluate & Refine (Does the nature-inspired solution work? How does it perform?)

- Test thermal simulations of facades and structural elements under sun loads.
- Measure internal temperatures and material expansion to validate design.

5. Integrate:

- Implement hybrid passive cooling strategies in structural and envelope design for long-term durability and energy efficiency.

COMMON PROBLEM (FOR INSPECTORS) EXERCISE 4: IDENTIFYING SUBTLE CODE VIOLATIONS IN LOW VISIBILITY AREAS

1. Define the Challenge (What is the problem?)

The challenge is subtle violations being missed due to the lack of technology, poor visibility, distance issues, et. cetera. The desired outcome is to be able to detect hidden code violations quickly and accurately regardless of the location and environment.

2. Emulate Nature's Strategies (How does nature solve this?)

- **Owls:** Exceptional vision in low light and ability to detect subtle motion.
- **Bats:** Echolocation to detect obstacles in darkness.
- **Ants:** Systematically explore and map complex spaces and terrain efficiently.



Figure 1.11. – Owls need only 10 lux to see in an environment.
© mark broadhurst, Pexels.com

"…Owl is developing thermal-ranging 3D sensors that, the company claims, can detect objects in any light or visibility conditions…" – Mobility Engineering Tech

3. Apply the Strategy i.e. Biology to Design (Translating biological strategies into building concepts)

1. Implement AI-assisted imaging or thermal cameras to identify hidden anomalies. (Owl)
2. Implement sonar or acoustic scanning akin to bat echolocation to detect voids or structural defects. (Bats)
3. Use systematic inspection patterns inspired by ants to ensure no space is overlooked. (Ants).

These patterns can be streamlined by investing in CMT or Construction Management Technology including defect management software. This uses cameras and drones to inspect large areas quickly and collect images for evaluation. Also executing remote inspections using digital tools like 360 degree cameras, Virtual Reality headsets, laser scanners,

and thermal imaging allows for inspecting hard to reach areas or hazardous areas effectively, quickly and safely.

This also means having a process and following it, for example a typical inspection life cycle is as follows below:

1. Planning & Scheduling
2. Stage-Based Inspections
    1. Foundation
    2. Rough-In
    3. Framing/Structural
    4. Final Inspection
3. Documentation and Checklists
4. Enforcement and Follow-Up
5. Record Keeping

4. Evaluate & Refine (Does the nature-inspired solution work? How does it perform?)

- Test the detection systems on sample buildings and hidden spaces.
- Track inspection accuracy and speed compared to traditional methods.

5. Integrate:

- Combine visual, thermal, and acoustic tools with systematic workflows for efficient, thorough inspections.

COMMON PROBLEM (FOR CONTRACTORS)

EXERCISE 5: MANAGING ON-SITE HEAT AND MATERIAL PERFORMANCE

1. Define the Challenge (What is the problem?)

Preventing or minimizing worker death and poor material performance in high-heat conditions. The desired outcome being to keep workers safe and alive and to maintain material performance in high-heat conditions.

2. Emulate Nature's Strategies (How does nature solve this?)

- **Camels:** Regulate body temperature to survive in extreme heat.
- **Termite mounds:** Passive cooling and ventilation strategies.
- **Lotus leaves:** Reflect solar heat to stay cool.

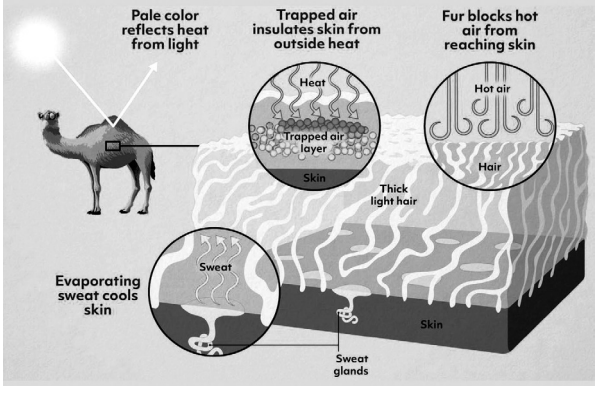


Figure 1.12. – How camels stay cool in extreme heat © Ask Nature, https://asknature.org/strategy/how-a-camels-fur-coat-keeps-it-cool/

3. Apply the Strategy i.e. Biology to Design (Translating biological strategies into building concepts)

- Provide shade structures and reflective temporary coverings inspired by lotus leaves.
- Implement natural ventilation corridors on-site inspired by termite mounds.
- Use heat-adaptive scheduling like camels resting during peak heat, shifting work hours to cooler periods.

4. Evaluate & Refine (Does the nature-inspired solution work? How does it perform?)

- Monitor on-site temperatures, worker comfort, and material quality under different mitigation strategies.

5. Integrate:

- Adopt heat-mitigating site planning, temporary shading, and adaptive scheduling for safer, more efficient construction.

PART 1 – BIOMIMICRY AND REGENERATIVE DESIGN KNOWLEDGE CHECK (5 QUESTIONS)

1. What is the primary goal of Biophilic Design?

A. Improve the performance of buildings in relation to the environment

B. Enhance occupant well-being and emotional connection to nature

C. Mimic nature's strategies for technical innovation

D. Reduce energy consumption through passive cooling

2. Which of the following best describes the goal of Biomimicry?

A. To create spaces that reduce stress and improve mental health

B. To mimic nature's strategies to improve performance and sustainability technical challenges in the built environment.

C. To enhance the aesthetic appeal of buildings through natural elements.

D. To increase biodiversity within urban environments.

3. Which of the following is an example of Biomimicry?

A. Adding indoor plants to an office space

B. Designing a façade inspired by a pinecone's ability to open and close

C. Using natural wood for flooring

D. Incorporating water features into a lobby

4. What is the key difference between Biophilic Design and Biomimicry?

A. Biophilic Design focuses on technical innovation, while Biomimicry focuses on human well-being

B. Biophilic Design uses nature for experiences, while Biomimicry uses nature for solutions

C. Biophilic Design is used by engineers, while Biomimicry is used by architects

D. Biophilic Design is concerned with building performance, while Biomimicry is concerned with aesthetics

5. **Which of the following is NOT one of the six overarching Biomimicry Life's Principles?**
   A. Be Resourceful with Material and Energy
   B. Use Life-friendly Chemistry
   C. Focus on Aesthetic Engagement
   D. Adapt to Changing Conditions

This concludes Part 1 of the course.

Let's continue to Part 2.

PART 2 – BIOMIMICRY IN STRUCTURE AND THERMAL SYSTEMS

Learning Objective No. 2: Identify existing natural systems that are being developed into advanced solutions for structural optimization and passive climate control.



BIOMIMICRY FOR STRUCTURAL EFFICIENCY

OVERVIEW

Take a moment to stop reading and look at your forearm, did you know the bones in your body have relevance to the architecture you see being structurally maintained today? Learn how below.

1. Bone & Trabecular Architecture

Natural Model

- Cortical + trabecular bone demonstrates hierarchical optimization. *(refer to Fig 2.1 below)*

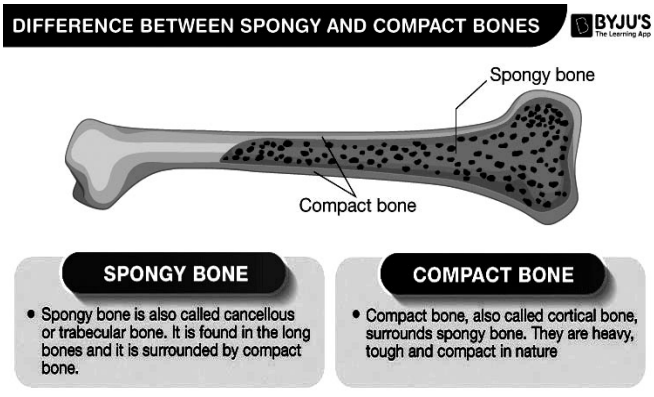


Figure 2.1. – Difference between Spongy and Compact Bones © ByJus

- Trabecular bone distributes material only where needed, following principal stress trajectories (Wolff's Law).
  - *"Wolff's Law is the idea that natural healthy bones will adapt and change to adapt to the stress that it is subjected to. For example, if the bones are subjected to heavier and heavier loads, they will naturally reconstruct themselves to accommodate that weight. This is how bones typically respond to stress."* – *WebMD*
- Exhibits high strength-to-weight ratio, anisotropy, and void optimization.
  - *Anisotropy* is the property where a material's physical characteristics (like strength, optical properties (think glass), etc.) change depending on the direction they are measured in.
  - *Void optimization in this context means eliminating or removing voids in engineering designs. For example, removing unnecessary materials or ensuring internal voids can be removed. Also referred to as topology optimization.*

Principle(s)

- Topology optimization
- Stress-aligned lattices
- Gradients of density: Denser material where stresses peak; lighter where stresses fall off.

AEC Translation(s)

Lighter Columns

- 3D-printed steel or concrete columns with void patterns aligned with load paths, reducing material while preserving axial capacity.
- Optimized "bone-mimetic" branching at column heads to reduce punching shear; Punching shear is what occurs when a concentrated load is applied to a small area of a slab.

Optimized Slabs

- Voided slabs with stress-mapped cellular voiding patterns (vs. uniform bubble decks).
- Ribbed slabs where rib directions follow principal bending moments.

Diagrid Systems

- Bone's stress-based anisotropy supports angle-optimized diagonals—diagrid density increases near high shear zones (i.e. building corners), decreases elsewhere. (Refer to Figure 2.2)



Figure 2.2. – High rise with a Diagrid Structural System located in Milano, Italia © Earth Photart, Pexels.com

Building Example(s)

a. MX3D Bridge, Amsterdam, The Netherlands

- World's first 3D-printed stainless-steel bridge.
- Structural optimization guided by stress trajectories, like trabecular patterns.
- Substantial material savings versus comparable solid steel.

b. One Airport Square, Ghana, Africa

- Diagrid facade structure uses angle optimization (a trabecular principle).
- Reduced steel tonnage + enhanced lateral resistance.

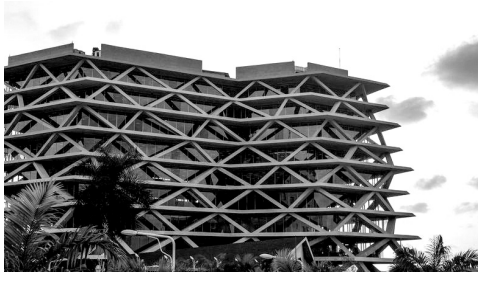


Figure 2.2.1. – Diagrid façade shown of One Airport Square in Ghana, Africa
© newofficeafrica.com

Emerging AEC Application

- Topology-optimized column/beam nodes for steel diagrids.
- Biomimetic 3D-printed concrete columns.

2. Diatoms (Silica Micro-Shells)

A diatom is *"a microscopic, single-cell form of marine or fresh-water algae, having siliceous cell walls..."* *– ForensicFiles*



Figure 2.3. – Diatoms produce 20-30% of the air we breathe.
© Diatoms.org

Natural Model

- Exoskeletons made of porous silica with:
  - Hexagonal micro-lattices
  - Ribbed frameworks
  - Perforation patterns for lightweighting without losing stiffness.
- Exceptional buckling resistance

Principle(s)

- Porosity-based stiffness optimization
- Perforation fields optimized for bending and shear
- Local reinforcement with minimum material

AEC Translation(s)

Lighter Façade Panels / Slabs

- Ultra-high-performance concrete (UHPC) or metal panels with diatom-inspired perforation fields optimized for bending and shear.
  - Diatoms, specifically diatomaceous earth (DE), are a natural, silica-rich material used in Ultra-High-Performance Concrete (UHPC). It replaces expensive silica fume and acts as a supplementary cementitious material to create a stronger, more durable, and eco-friendly concrete.
    - Diatomaceous earth is primarily composed of amorphous silica which are the fossilized skeletal remains of diatoms.



Figure 2.4. – You're looking at the first UHPC bridge constructed in the United States; Location: Wapello County, Iowa © FHWA DOT

- Thin-shell slab geometries with rib-like stiffeners that mimic diatom frustule ribs.

Column Jackets / Tubular Columns

- Diatom-inspired ribbed tubular forms increase Euler buckling capacity (the Euler Buckling Load formula allows you to predict the buckling load of slender columns) with minimal added mass.

Diagrid Nodes

- 3D-printed node connectors with diatom-like perforated-but-stiff geometry, reducing weight and improving fabrication efficiency.

Building Example(s)

a. Zaha Hadid Architects – "Striatus Bridge"

- Arched masonry footbridge composed of 3D-printed concrete blocks (dry stack with no mortar or reinforcement)
- Masonry blocks arranged in diatom-like compression-only geometry.
  - "Striatus is an unreinforced concrete structure that achieves strength through geometry. In arched and vaulted structures, material can be placed precisely so that forces can travel to the supports in pure compression." *– ThePlan It*



Figure 2.4.1. – Striatus Bridge by Zaha Hadid Architects
© Photograph by Naaro, Zaha Hadid Architects

b. Al Bahar Towers Facade

- Mashrabiya shading screen replicates porous lattice mechanics.
- Reduces solar load/heat gain; Has a lightweight fiberglass structure

c. Emerging AEC Application

- Rib-stiffened Ultra-High Performance Concrete (UHPC) façade panels considerably thinner than conventional Glass Fiber Reinforced Concrete (GFRC).

3. Nacre (Mother of Pearl)

The iridescent, tough inner lining of mollusk shells

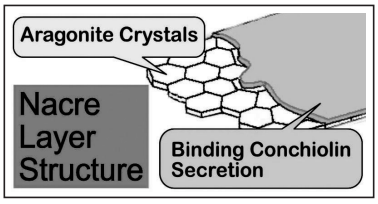


Figure 2.5. – The layer structure of the Mother of Pearl. © HERMJ

Natural Model

Made of microscopic "bricks" of a mineral called aragonite, laced together with a "mortar" made of organic material. This bricks-and-mortar arrangement gives mollusks their strength

> **"…the "bricks" are actually multisided tablets only a few hundred nanometers in size. Ordinarily, these tablets remain separate, arranged in layers and cushioned by a thin layer of organic "mortar." But when stress is applied to the shells, the "mortar" squishes aside and the tablets lock together, forming what is essentially a solid surface. When the force is removed, the structure springs back, without losing any strength or resilience.**
>
> **This resilience sets nacre apart from even the most advanced human-designed materials. Plastics, for example, can spring back from an impact, but they lose some of their strength each time. Nacre lost none of its resilience in repeated impacts at up to 80% of its yield strength." – News UMich.edu**

Principle(s)

- Layered composites with:
  - Hard–soft alternating layers
  - Crack-arresting interfaces
  - Distributed micro-reinforcement
- Low-weight but extremely tough.

AEC Translation(s)

> **"This study explores enhancing the mechanical properties of fiber-reinforced polymer composites using a biomimetic approach inspired by nacre… The optimal configuration, with 25mm platelets, showed an 18% increase in impact strength…and a 115% increase in flexural strength…compared to monolithic laminates..." – Biomimetic nacre-inspired composites reinforced with glass fibers for enhanced strength**

Composite Slabs

- Glass/carbon fiber reinforced polymer (GFRP/CFRP) panels with nacre-inspired layered layups, allowing:
  - Thinner slab sections
  - High damage tolerance during impact (e.g., seismic, blast, etc.)

Column Wrappings

- Nacre-patterned composite wraps that improve confinement while reducing mass compared to purely steel jackets.

Diagrid Joints

- Laminated composite joints that use brick-like micro-tessellation to spread stress and prevent sudden brittle failure.

Building Example(s)

a. HSB Turning Torso (Sweden)

- Laminated composite façade panels use toughened, layered structures to resist wind loads.
- Nacre-inspired digital lamination used in panel design.



Figure 2.6. – HSB Turning Torso by Santiago Calatrava is based on Twisting Torso, a white marble sculpture by Calatrava; Location: Malmö, Sweden

© Amjad Sheikh, Wikipedia

b. Bridge Example: FRP wrapped seismic columns

- Nacre principles used to deflect cracks and increase ductility.
- Results: Increase in energy dissipation.

c. Emerging AEC Application

- Nacre-inspired hybrid composite slabs:
  - Significantly lighter than steel–concrete composite decks
  - Increased impact resistance

4. Trees (Stem-Tapering, Branching, Reaction Wood)

Natural Model

- Trees are optimized towers:
  - Tapering trunks reduce weight while maintaining stability.
  - Branching follows stress paths and distributes loads efficiently.
  - Wood thickens where bending stresses occur.

Principle(s)

- Variable cross-sections
- Stress-adaptive geometry
- Load-path continuity

AEC Translation(s)

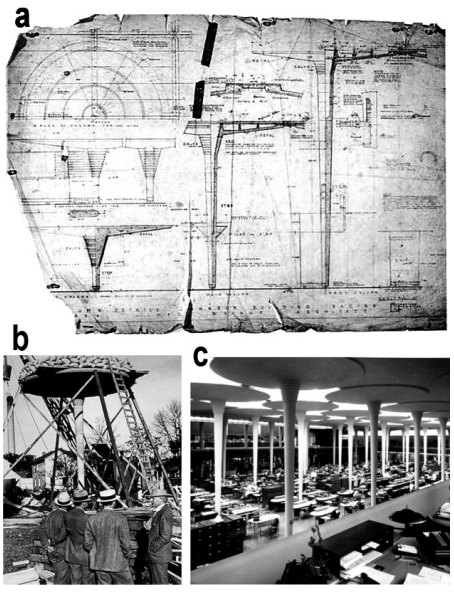


Figure 2.7. – (a) Cross-section of the columns (b) Load testing on tubular mushroom column by F.L. Wright in 1938; (c) tubular mushroom columns supporting a glass ceiling, Johnson's Wax Building, 1939, by F.L. Wright (Lipman and Wright, 1986). © ScienceDirect

Lighter Columns

- Tapered concrete or steel columns with diameters calculated from moment and buckling demand, not uniform code minimums. (performance based design)
- Tree-like branching capitals (e.g., Gaudí-inspired forms) decrease shear and allow for thinner slabs.

Diagrid Systems

- Tree-branching logic equates to diagrid density being near the base, thinning upward.
- Continuously curved members reduce stress concentrations at nodes.

"…Wright's mushroom columns, inspired by natural trees structural strength, remain one of the most remarkable structural designs in the 20th century architecture…" – ScienceDirect

Slab–Column Transitions

- Flared column tops inspired by tree trunks merging into branches:
  - Less punching shear
  - Thinner flat slabs
  - Reduced reinforcement congestion

Real World Example(s)

a. Centre Pompidou-Metz (Metz, France)

- Roof is a branching hexagonal timber lattice inspired by tree canopies.
- Material minimization via tapered, curved glulam elements.

b. Basílica de la Sagrada Família Columns (Barcelona, Spain)

- Hyperboloid/tapered columns following catenary (gravity-driven) tree logic.
- Demonstrates nature's branching load paths.

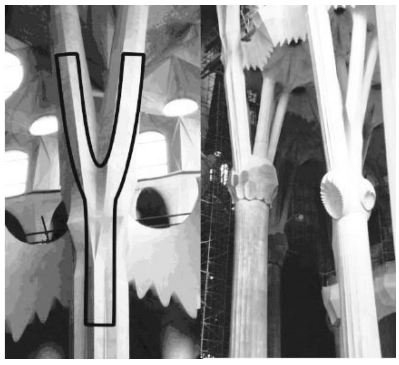


Figure 2.8. – The Columns of La Sagrada Familia in Barcelona, Spain by Antoni Gaudi © Julian Francis Vincent, Research Gate

"Columns in Gaudi ' s Sagrada Familia. Left: a branching column with the outline of a divided tree superimposed. Note the difference in shape of the internal corner. Right: the lumps are probably Gaudi ' s solution to the inevitable stress concentrations which the sharp corners of his design will engender." – Julian Francis Vincent Vincent (ResearchGate)

c. Emerging AEC Application

- High-rise diagrids with variable member density (thick at base → thin upward), mimicking trunk tapering.

5. Fungi Mycelium Networks

Natural Model

Mycelium, the root system of fungi (think mushrooms), forms a highly connected network that acts as a biodegradable building material. This natural material has excellent strength-to-weight ratios and can be used for structural reinforcement while being environmentally friendly.

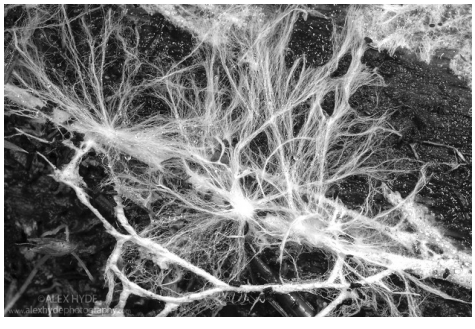


Figure 2.9. – Fungi Mycelium Networks © mayneconservancy.ca

Principle(s):

- Microfibrous network that forms a strong, lightweight material with high resilience to stress.
- Biodegradability means mycelium-based materials can return to the earth, providing a closed-loop system.

AEC Translation(s):

1. **Mycelium-Based Structural Panels:**
   - Mycelium composites for load-bearing structures, insulation, and wall panels.
2. **Fungus-Inspired Building Bricks:**
   - Biodegradable fungal bricks that can be grown on-site, reducing the carbon footprint.

Real-World Example(s):

a. The Growing Pavilion (Paris, France)

- This pavilion was built using mycelium-based bricks to demonstrate the potential of biodegradable materials for the future of sustainable construction. The mycelium material is both lightweight and resilient, yet biodegradable at the end of its lifecycle.

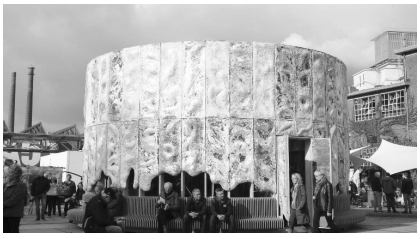


Figure 2.10. – The Growing Pavilion © TheGrowingPavilion.com

B. Greensulate and MycoComposite™ (USA)

- Greensulate is an insulation that can be grown in place and is created using fungi and agricultural waste.
- MycoComposite™ is a compostable material used for packaging it's created by growing mycelium (mushroom roots) and agricultural matter. A response to the problem of sytrofoam and plastic waste.

"Greensulate is an R-3-per-inch rigid insulation material that is made from intertwining mycelium (rootlike filaments of a fungus) that are grown in agricultural waste materials (primarily seed hulls) under controlled conditions. The mycelium forms a foam-like material that insulates reasonably well." – Building Green

BIOMIMICRY FOR PASSIVE THERMAL REGULATION

Format: **Natural Model(s) → Principle(s) → AEC Translation(s)**

OVERVIEW

A fun fact about passive thermal regulation is that hundreds of years ago traditional designs like wind catchers (badgirs) in Africa and Asia funneled cool air inside a structure while pushing hot air out—an early form of natural air conditioning if you will.

1. Termite Mounds (Macrotermes)

Natural Model

Termite mounds maintain consistent interior temperatures despite extreme external heat conditions

This is achieved by using:

- Vertical chimneys for buoyancy-driven flow
- Lateral flutes & porous walls for pressure equalization
- Daily thermal mass charging/discharging
- Driven convection from internal nest heat



Figure 2.11. – A termite mound in Nigeria, Afrika © By Gwanki – Wikipedia

Principle(s)

- Pressure differential ventilation
- Buoyant air column convection (stack effect)
- Porous, thermal-mass heavy walls buffer diurnal swings (think Trombe wall)

AEC Translation(s)

1) Stack Ventilation

- Central atriums or thermal chimneys draw warm air upward.
- Inlets at lower levels admit cooler air.
- Exterior flutes = architectural fins that induce cross-ventilation.

2) Night-Flushing

- Heavy mass walls (concrete, rammed earth, brick):
  - absorb heat during the day
  - release stored heat at night via controlled ventilation
- Eastgate Centre uses this principle with 90% HVAC reduction. (more about this in Part 4)

3) Pressure Equalization Façades

- Perforated double skins inspired by termite mound porosity.
- Stabilize indoor climate by dampening wind pressure and facilitating passive exfiltration.

2. Cactus (Saguaro, Barrel Cacti)

Natural Model

Cacti survive extreme desert heat using:

- Ribs/folds that expand, contract, and create self-shading
- Thick epidermis + waxy coating for radiative reflection
- Spines as micro-radiators + convective turbulence generators
- High thermal inertia (water)
- Nighttime carbon dioxide (CO_2) uptake (CAM cycle) = nocturnal "cooling cycle" because stomata open at night to collect carbon dioxide (CO2) and allow it to diffuse into the mesophyll cells.



Figure 2.12. – "…A difference between a saguaro cactus and a barrel cactus is size and height…" © Plantsnap

"…Crassulacean acid metabolism (CAM) is a photosynthetic adaptation to periodic water supply, occurring in plants in arid regions (e.g., cacti) or in tropical epiphytes (e.g., orchids and bromeliads). CAM plants close their stomata during the day and take up CO2 at night, when the air temperature is lower and water loss can be lowered by an order of magnitude…" – ScienceDirect

Principle(s)

- Self-shading rib geometry
- Radiative heat reflection
- Thermal mass buffering
- Surface micro-texture to manage boundary layers

AEC Translation(s)

1) Radiant Barriers

- High-reflectivity façades inspired by cactus epidermis wax layers.
- Micro-texturing panels (similar to cactus ribs) reduce net solar gain.

2) Self-Shading Geometry

- Vertical fins or folded façades mimic ribbing, creating:
  - a rhythmic sequence of shade pockets
  - reduced surface temperature
  - enhanced wind-washing for convective cooling

3) Thermal Mass + Night-Flush

- Cactus water reservoir → architectural thermal mass in:
  - adobe/rammed earth
  - high-performance PCM walls
- Night-flushing purges stored heat, mirroring nocturnal cactus metabolism.

3. Kangaroo Rat
Natural Model

The kangaroo rat maintains internal water balance and stable temperatures in extreme environments using:

- Counter-current heat exchange in nasal passages
- Burrow microclimates with steady cool temperatures
- Remarkably low radiant heat absorption (fur reflectance)



Figure 2.13. – Kangaroo Rat © Wikipedia

Principle(s)

- Heat exchange via narrow passageways
- Cool subsurface microclimates
- Radiant heat rejection

Minimum evaporative loss

AEC Translation(s)

1) Earth Coupling (Ground-Connected Cooling)

- Partially buried rooms acting as coolth reservoirs, similar to kangaroo rat burrows.
- Stable subterranean temperatures reduce cooling loads.

2) Narrow Ventilation Passages

- Duct or facade systems incorporating counter-flow heat exchange (pre-cooling of incoming air).

3) Radiant Heat Control

- Light, reflective roofs and walls mimicking fur albedo.
- Optimized roof shapes to reduce solar exposure.

4. Prairie Dogs
Natural Model

Prairie dog burrows maintain interior comfort in extreme climates using:

- Two openings at different elevations creating Venturi effect pressure differences
- Wind scoops that funnel outdoor air downward
- Thermal stratification zones within networks of chambers
- Convective tunnel geometry

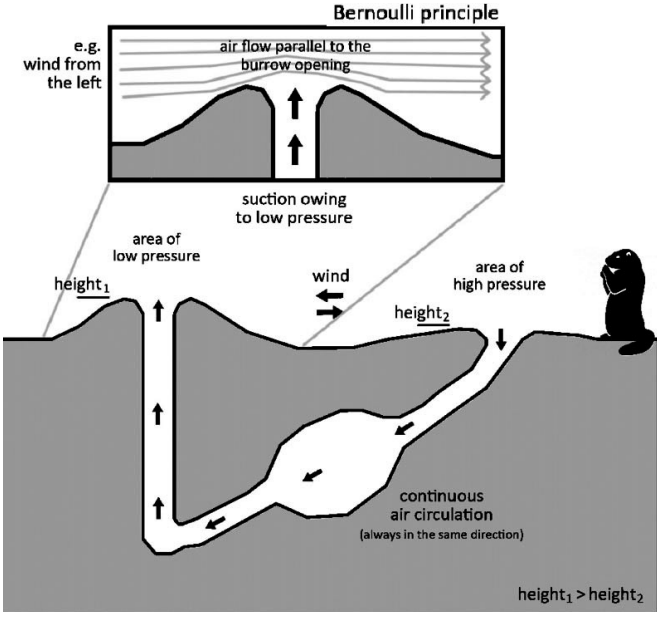


Figure 2.14. – A prairie dog burrow creates a Venturi effect which is a specific application or consequence of the Bernoulli Principle © Research Gate

Principle(s)

- Wind-driven exchange
- Pressure zoning across height differentials
- Subsurface insulation and thermal buffering

AEC Translation(s)

1) Wind-Scoop Ventilation

- Windward intakes + leeward exhausts replicate prairie dog burrow logic.
- Enhanced airflow even in low-wind conditions.

2) Venturi-Enhanced Stack Ventilation

- Chimneys tapered like burrow openings to accelerate air velocity.
- Works in passive schools/hospitals to improve fresh air rates.

3) Subsurface Temperature Zones

- Use of semi-buried spaces with stable temperatures:
  - garages
  - service corridors
  - thermal plenum zones

5. Beetle (Stenocara gracilipes)



Figure 2.15. – Beetle (Stenocara gracilipes) © Science.Org

Natural Model

The *Stenocara gracilipes* beetle survives in desert climates by collecting water from fog through its specialized exoskeleton.

The beetles back has a hydrophilic (water-attracting) and hydrophobic (water-repelling) surface pattern, which allows it to channel moisture from fog to its mouth.

It uses the thermal mass of the surface to store heat and regulate temperature.

Principle(s)

- Hydrophilic/hydrophobic surface patterning
- Micro-texture to capture and direct moisture
- Thermal mass for moisture condensation and temperature regulation

AEC Translation(s)

- **Fog Harvesting Façades**
  - Building skins or roof structures that capture water from fog using beetle-inspired hydrophilic/hydrophobic surfaces.
  - Water is then directed into storage systems or cooling towers.
- **Thermal-Activated Water Distribution**
  - Walls and surfaces designed to harvest and redistribute water through micro-textures, improving passive cooling and humidity regulation inside buildings.
- **Condensation-Enhancing Surfaces**
  - Micro-textured surfaces on windows or facades that encourage condensation for natural water collection and cooling, utilizing the thermally-regulated principles of the beetle's back.



6. Elephant Ear Leaves

Natural Model

The elephant ear plant, particularly its large leaves, utilizes transpiration *(the process of water movement through a plant and its evaporation from aerial parts, such as leaves, stems and flowers)* and the high surface area of its foliage to cool the surrounding environment.

The plant's large, flat leaves dissipate heat through evaporative cooling, increasing local humidity and reducing thermal load.

Principle(s)

- Large surface area for evaporation
- High transpiration rate
- Thermal mass to store heat

AEC Translation(s)

1. **High-Surface Area Green Walls**
   - Vertical gardens or green walls using large, broad-leaf plants (or biomimetic materials) to promote transpiration and cooling within building environments.
2. **Evaporative Cooling Roof Systems**
   - Roofs designed with plant-inspired forms (or synthetic analogs) that mimic the leaf's high surface area, improving evaporative cooling through natural ventilation.
3. **Thermal Mass Green Façades**
   - Incorporating foliage or vegetation in façade systems to help absorb and gradually release heat, reducing the need for mechanical air conditioning. The foliage acts as a buffer, controlling thermal fluctuations.



Figure 2.17. – Lotus Leaf (Nelumbo nucifera) © Illinois Wildflowers

7. Lotus Leaf (Nelumbo nucifera)

Natural Model

The lotus leaf is known for its superhydrophobic properties, meaning it can shed water efficiently due to the unique microstructure of its surface.

This reduces heat absorption by minimizing water's contact with the leaf *(the minimized water contact creates air pockets which are poor heat conductors i.e. less heat transfer via conduction)*, and the structure can also reflect light, helping to keep the surface cooler in hot environments.

Principle(s)

- Superhydrophobic surface for moisture resistance
- Solar reflectance properties
- Reduced heat absorption via water repulsion

AEC Translation(s)

1. **Water-Shedding Roofs**
   - Roof systems with micro-textured coatings inspired by lotus leaves, designed to shed rainwater efficiently while minimizing heat absorption, keeping roofs cooler in hot climates.
2. **Self-Cleaning Facades**
   - Glass or facade materials designed to repel water and dirt, reducing maintenance while improving thermal performance by minimizing moisture retention and increasing solar reflectivity.

3. **Hydrophobic Coatings for External Walls**
    - Buildings using hydrophobic materials to reduce the effects of rainwater, which can increase heat retention and reduce cooling load by preventing moisture buildup.

8. Marine Slugs

Natural Model

Marine nudibranchs have evolved adaptive mechanisms that allow them to regulate their temperature in varying underwater environments.



Figure 2.18. – Nudibranchs (Marine Slugs) © Géry PARENT Wikipedia

Their flexible, amorphous bodies can adjust their surface area to the surrounding water temperature, offering efficient insulation and reducing energy loss.

Principle(s)

- Surface area manipulation for heat regulation
- Amorphous, flexible structure for insulation
- Adaptive thermal resistance based on environmental conditions

AEC Translations(s)

1. **Dynamic Insulating Surfaces**
    - Building skins or facades that can adapt to environmental temperature shifts, using materials with responsive properties that expand or contract to regulate heat flow.
2. **Flexible Thermal Barriers**
    - Systems that mimic nudibranchs' body flexibility, employing dynamic materials that enhance insulation when the temperature rises, providing better passive thermal control.
3. **Adaptive Roof and Façade Panels**
    - Roof and façade systems that expand or contract based on temperature, reducing the need for mechanical heating/cooling systems and improving energy efficiency.

9. Sensitive Plant (Mimosa Pudica)

Natural Model

The sensitive plant Mimosa pudica can change the position of its leaves in response to sunlight, closing them when exposed to extreme heat. This self-adjustment helps the plant avoid excessive heat absorption and water loss. The plant's leaves use photo-responsive mechanisms to regulate their exposure to sunlight.



Figure 2.19. – Mimosa Pudica (Sensitive Plant) © House Beautiful

Principle(s)

- Photo-responsive movement for thermal regulation
- Self-adjusting geometry
- Dynamic response to environmental stimuli

AEC Translations(s)

1. **Photo-responsive Façades**
    - Dynamic façades that adjust their position and geometry throughout the day, opening or closing based on sunlight intensity, reducing solar heat gain and improving indoor thermal comfort.
2. **Self-Adjusting Shading Systems**
    - Exterior shading elements (e.g., louvers or panels) that automatically adjust to block direct sunlight and reduce heat absorption, inspired by the movement of *Mimosa pudica* leaves.
3. **Smart Window Films**
    - Window films or coatings that adjust opacity in response to solar heat gain, reducing the need for mechanical shading and cooling systems, enhancing passive temperature regulation.



Figure 2.20. – Fungi Mycelium © TasteForLife.com

10. Fungi Mycelium

Natural Model

Fungi mycelium networks are highly effective at moisture regulation, able to absorb, store, and release moisture as needed.

The dense, fibrous structure of mycelium also serves as an excellent natural insulator, helping maintain a stable temperature in its environment.

Principle(s)

- Moisture absorption and release
- Natural insulation through fibrous structure
- Biodegradable, sustainable material properties

AEC Translations(s)

1. **Mycelium Insulation Panels**
    - Mycelium-based insulation materials used in building envelopes, providing natural thermal regulation and moisture control while being biodegradable and eco-friendly.
2. **Moisture-Regulating Building Materials**
    - Walls and flooring systems using mycelium or mycelium-based composites that adapt to humidity levels, absorbing excess moisture in humid conditions and releasing it in drier environments, maintaining a balanced indoor climate.
3. **Biodegradable Thermal Barriers**
    - External cladding materials that act as natural thermal insulators while being environmentally sustainable, offering high thermal resistance while also reducing the building's carbon footprint.

11. Whale Blubber

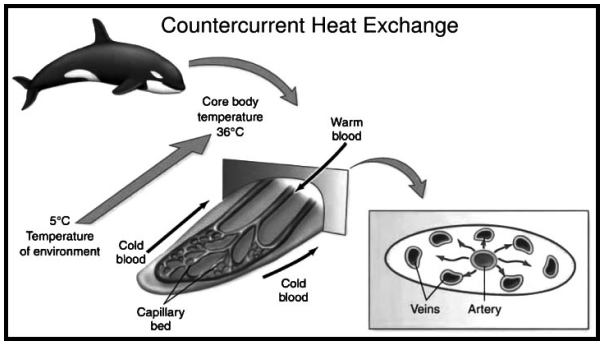


Figure 2.21. – Whales regulate their internal temperature to keep it constant regardless of the environmental temperature © Pcristales3

Natural Model

Whales have thick layers of blubber that provide both insulation and buoyancy. This fat layer helps to maintain stable internal body temperatures by reducing heat loss in cold waters and preventing overheating in warmer environments.

Principle(s)

- Thermal insulation via fat layers
- Adaptive thickness based on environmental temperature
- Heat storage and retention

AEC Translations(s)

1. **Fat-Layered Insulation**
   - Multi-layered thermal insulation systems in buildings inspired by whale blubber, using materials that store and release heat depending on ambient temperature.
2. **Thermal Insulating Walls**
   - Walls incorporating bio-inspired insulative materials (e.g., fat-based composites or foam materials) to store heat in cold conditions and release it in hot conditions, reducing heating and cooling demands.
3. **Adaptive Building Insulation**
   - Insulating systems that change their thickness or composition depending on external temperature, much like the varying thickness of whale blubber, providing more efficient insulation during seasonal temperature fluctuations.

12. Penguin Feathers

Natural Model

Penguins' feathers are designed to keep them warm in extremely cold environments. Their feathers have a unique structure, with a dense layer of insulation that traps air and helps retain body heat.

Additionally, their outer feathers are highly waterproof, preventing heat loss from water exposure.

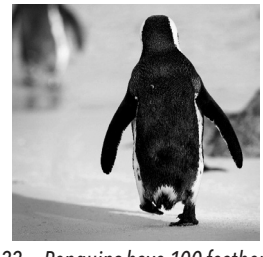


Figure 2.22. – Penguins have 100 feathers per inch © Photo by Jean van der Meulen, Pexels.com

Principle(s)

- Microstructural air pockets for insulation
- Waterproof outer layers for thermal retention
- Feather density for efficient heat trapping

AEC Translations(s)

1. **Micro-Textured Insulating Surfaces**
   - Building facades or roof systems with micro-structured coatings inspired by penguin feathers, which trap air and reduce heat loss, providing insulation without bulk.
2. **Waterproofing Building Envelopes**
   - External cladding or roofing systems that mimic the waterproof nature of penguin feathers, using hydrophobic materials that keep the interior dry and maintain thermal performance.
3. **High-Density Insulating Materials**
   - Wall systems with densely layered insulating materials, creating air pockets similar to the feathers' structure, to enhance thermal insulation in extreme climates.

13. Swallowtails (Butterfly Wings)

Natural Model

Swallowtail butterflies have evolved wings that help regulate their body temperature by reflecting sunlight and promoting evaporative cooling. Their wings have a unique microstructure that helps dissipate heat and reflect infrared radiation, which prevents overheating in hot environments.



Figure 2.23. – Swallowtail Butterfly © By Uoaei1 – Wikipedia

Principle(s)

- Reflective surfaces to minimize solar gain
- Microstructure for enhanced heat dissipation
- Evaporative cooling through wing surface area

AEC Translations(s)

1. **Reflective Façades**
   - Building envelopes designed with highly reflective surfaces, inspired by butterfly wings, to reduce solar heat gain while maintaining aesthetic appeal. These surfaces can use materials that reflect infrared radiation while allowing visible light to pass through.
2. **Evaporative Cooling Systems**
   - Roofs or exterior walls that mimic the swallowtail butterfly's wing texture, facilitating heat dissipation through evaporation. This could involve micro-textured panels or coatings that promote passive cooling.
3. **Adaptive Shading Systems**
   - Façades or shading devices with biomimetic patterns inspired by butterfly wings, where the surface changes to reflect more or less sunlight based on temperature or time of day, providing active solar control.

14. Whip Spiders (Tailless Whip Scorpions)

Natural Model

Whip spiders, living in hot, dry environments, regulate their temperature by controlling evaporative cooling.

Their long, flexible legs and body surfaces allow for more effective heat dissipation, and they make use of small-scale geometry to enhance heat loss and reduce thermal stress.

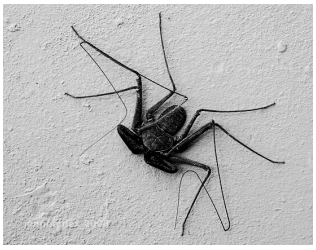


Figure 2.24. – Tailless whip scorpion spotted at a home in Hermosillo, Sonora, Mexico © José Eugenio Gómez Rodríguez Blogs.ucl.ac.uk

Principle(s)

- Large surface area for heat dissipation
- Evaporative cooling through surface geometry
- Enhanced convection by long, flexible body structures

AEC Translations(s)

1. **Evaporative Cooling Facades**
   - Buildings designed with long, flexible shading elements or façade systems, inspired by the whip spider's legs, that maximize surface area for increased heat dissipation and passive cooling.
2. **Thermal Buffering Materials**
   - Wall systems using geometries that enhance airflow and evaporative cooling by mimicking the whip spider's surface structure to create an increased surface area for heat exchange.
3. **Flexible Shading Systems**
   - Adjustable external shading systems that increase or decrease surface area based on external temperature, similar to the whip spider's ability to adjust body posture to optimize cooling.

15. Honeybee Hives

Natural Model:

Honeybees build their hives in highly efficient hexagonal patterns, which optimize space utilization and thermal insulation. The honeycomb structure creates minimal air resistance, maximizing internal thermal stability.



Figure 2.25. – Honeybee Hives © Archana GS , Pexels.com

Principle(s):

- Hexagonal tessellation minimizes material use while maximizing space and strength.
- Optimal airflow through the hive's structure allows for precise temperature control without energy-intensive cooling or heating systems.

AEC Translations(s):

1. **Hexagonal Facade Patterns for Thermal Insulation:**
   - Modular hexagonal tiles for walls and roofs that trap air in natural cavities, offering passive cooling or insulation.
2. **Beehive-Inspired Thermal Mass:**
   - Wall sections designed to mimic the honeycomb structure for passive thermal management in buildings.

Real-World Example(s):

- **The Eden Project** (Cornwall, UK): The hexagonal honeycomb-inspired geodesic domes that make up the biomes mimic the thermoregulation properties of beehives.

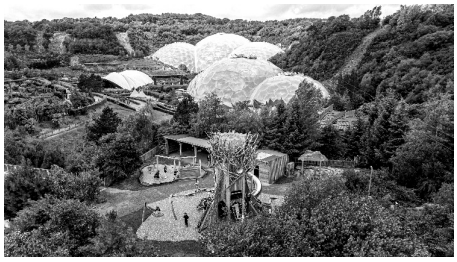


Figure 2.26. – The Eden Project © edenproject.com

The structure maximizes natural light while maintaining a stable internal temperature, minimizing the need for artificial heating and cooling.

PART 2 – BIOMIMICRY IN STRUCTURE AND THERMAL SYSTEMS | KNOWLEDGE CHECK (5 QUESTIONS)

1. **What principle does trabecular bone demonstrate that is applied in structural optimization?**
   A. Stress-aligned lattices and void optimization
   B. High thermal mass and buoyancy-driven flow
   C. Hydrophilic and hydrophobic surface patterning
   D. Reflective surfaces and evaporative cooling

2. **Which natural model inspired the design of diagrid systems with angle-optimized diagonals?**
   A. Termite mounds
   B. Diatoms
   C. Bone and trabecular architecture
   D. Nacre (Mother of Pearl)

3. **What is a key feature of diatom-inspired façade panels?**
   A. High reflectivity to reduce solar heat gain
   B. Perforation fields optimized for bending and shear
   C. Hydrophobic coatings for water resistance
   D. Layered composites for crack arresting

4. **How does nacre (Mother of Pearl) achieve its exceptional toughness?**
   A. MX3D Bridge, Amsterdam
   B. Centre Pompidou-Metz, France
   C. Al Bahar Towers, UAE
   D. Striatus Bridge, Zaha Hadid Architects

5. **Which building example demonstrates tree-inspired branching load paths?**
   A. MX3D Bridge, Amsterdam
   B. Centre Pompidou-Metz, France
   C. Al Bahar Towers, UAE
   D. Striatus Bridge, Zaha Hadid Architects

This concludes Part 2 of the course.

Let's continue to Part 3.

PART 3 – BIOMIMICRY IN WATER MANAGEMENT AND MATERIAL SURFACE SCIENCE

Learning Objective No. 3: Identify existing natural systems that are being developed into advanced solutions for water management and material surface science.



BIOMIMICRY FOR WATER MANAGEMENT

OVERVIEW

Pop quiz question, what does every high-rise have on its rooftop? Yes, of course a roof but they always have a roof rig for the window washing equipment. Now imagine not needing that equipment at all and thus no line item for that cost. So, what cleans the windows? Rainfall. Look to the Lotus Leaf and learn how below.

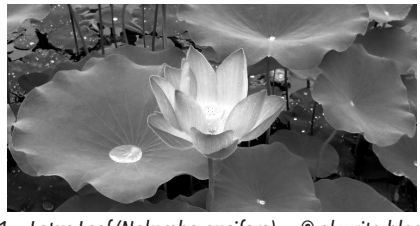


Figure 3.1. – Lotus Leaf (Nelumbo nucifera) © akwrite.blogspot.com

1. Lotus Leaf (semi-aquatic plant)

Natural Model

- How do Lotus leaves remain so beautiful amidst the muddiest ponds?

  The "Lotus Effect". It is comprised of several self-cleaning properties and mechanisms as follows: A superhydrophobic surface, a unique contact angle (higher than 160° with a sliding angle lower than 5°) and a dense layer of wax tubules on the upper epidermis.

  "…On the lotus leaf surface, the adhesion between the water droplet and dust particle is stronger than the adhesion between the dusts and the surface, hence the spherical water drops pick up the dust particles while rolling off the lotus leaf…" – PMC NCBI NIH.gov

- The microscopic architecture of the Lotus leaf means that water can't penetrate nanofolds on the surface, leaving air pockets below. The water droplets become suspended in the Cassie-Baxter state/law/equation (see below) and are able to roll off the leaf picking up dirt as they do so, thus *cleaning* the leaf.

  "…The more commonly encountered equation is that of Cassie-Baxter [2]. It describes the contact angle on a porous surface. Instead of having two different surface chemistries as in Cassie law, the surface is now composed of solid surfaces and areas where the drop is in contact with air…" – Biolin Scientific

- **Principle(s)**
  - Hierarchical micro/nano texture + low-surface-energy epicuticular wax
    - Low-surface-energy epicuticular wax is a waxy coating that forms a whitish film *(refer to Figure 3.2.1, page right)* on the outer surface of leaves, fruits and other plant organs. It has the highest ultraviolet light (UV) reflectivity of any known naturally occurring biological substance.



Figure 3.2.1. – Epicuticular wax on a plant © Dudleya brittonii, Wikipedia

  - Cassie-Baxter wetting state
  - Minimal lag which equates to a ultra-low roll-off angle that is less than five degrees
  - Superhydrophobic Self-Cleaning + Water Repellency

- **AEC Translations(s)**
  - **Self-Cleaning Façades & Roofs**
    - Nanotechnology textured paints/coatings *(widely used on buildings like the Technoseum in Germany)* keep exteriors clean with rainfall only which equates to reduced maintenance and very little chemical cleaning.



Figure 3.2.2. – Technoseum in Mannheim, Germany © Museu.ms

- **Anti-Fouling Building Envelopes**
  - Applied to glass, metal, or concrete prevents mold/algae growth and reduces urban heat island effect by keeping surfaces reflective with a high albedo.
- **Water-Repellent Membranes**
  - Roofing membranes that shed water instantly which in turn reduces leakages, ice damming, and material degradation.
  - Provides protection against rust, corrosion, graffiti, and provides electrical circuit protection preventing outages due to moisture infiltration.

2. Shark Skin

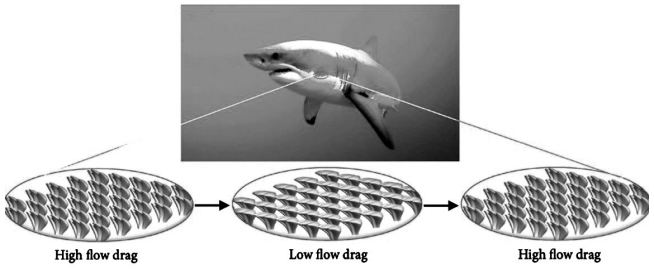


Figure 3.3. – Shark skin is covered in tiny scales called dermal denticles which reduce drag for faster, quieter swimming © Arstechnica

Natural Model

- Why are sharks silent assassins of the sea?
  - Because of their skin – which is covered by dermal denticles (i.e. miniscule and flat "V" shaped overlapping scales) with three to five longitudinal riblets or grooves per denticle. These denticles allow for sharks to decrease their drag and turbulence which permits them to swim faster, more quietly while also preventing organism attachment.

"…Olympian swimsuit designers have taken a page from the shark's playbook and created a fabric that mimics the exact proportion of the shark's denticles, hugely improving a swimmer's speed…" **– Ocean SI Edu**

- **Principle(s)**
  - Riblets and how they function reduce friction/drag and lower wall shear stress
  - Denticles prevent bacterial settlement
- **AEC Translations(s)**
  - **Anti-Fouling Finishes**
    - "Sharklet® is a synthetic surface inspired by the skin of sharks that deters colonization by certain disease-causing microbes. Because the artificial surface works without killing microbes, there is no selection for resistance. The surface topography is made of millions of microscopic diamonds that disrupt the ability for bacteria to adhere, colonize, or develop into biofilms. The Sharklet pattern is manufactured onto adhesive-backed skins that may be applied to high-touch areas to reduce the transfer of bacteria among people." – AskNature.Org
  - **Wind Turbines**
    - "When air passes over the turbine blade at the contact point between the blade and air, the velocity of the air comes to rest and the result is turbulence and skin friction," said University of Minnesota Professor Roger Arndt. "Riblets help to organize and channel that turbulence so it's less energetic and results in less energy loss. This delays lateral wind movement." The channeling effect was first noted in shark skin research in the 60s and 70s." – CSE UMN.edu

3. PINECONES

Natural Model

Pinecones exhibit hygroscopic properties, where their scales open and close in response to humidity.

In dry conditions, the scales close tightly to preserve moisture, while in high-humidity environments, they open to allow water absorption and dispersion.



Figure 3.4. – Pinecone ©Pineconee De Boever, Pexels.com

Principle(s)

- Hygroscopic movement driven by moisture changes
- Responsive geometry that adapts to environmental humidity
- Capillary action for water absorption and dispersion

AEC Translations(s)

1. **Responsive Cladding Systems**
   - Building skins or cladding systems that expand or contract in response to humidity levels, optimizing natural ventilation and moisture control within the building envelope.
2. **Water Dispersion Roofs**
   - Roof systems inspired by pinecone scales that open to capture rainwater and direct it into storage or distribution systems, particularly in humid environments.
3. **Humidity-Responsive Ventilation**
   - Humidity-sensitive windows or façade systems that open or close based on internal moisture levels, improving indoor air quality and passive water management.

4. MANGROVE ROOTS

Natural Model

Mangrove trees have adapted to live in saltwater by developing specialized root systems that filter out salt and conserve freshwater.

Their intricate root networks provide a way for the plant to trap sediments while filtering saltwater and retaining essential nutrients.



Figure 3.5. – Mangrove forest in its natural habitat. © Ksu&Eli Studio, Pexels.com

Principle(s)

- Filtration of saltwater through specialized root structures
- Capillary action for water retention and filtration
- Efficient nutrient absorption through complex root systems

AEC Translations(s)

1. **Saltwater Filtration Façades**
   - Vertical garden systems or building facades inspired by mangrove root structures that filter and purify water for irrigation or other uses, particularly in coastal regions.
2. **Water-Conserving Landscaping**
   - Building-integrated landscapes with root structures that help manage and filter rainwater runoff, preventing saltwater contamination and maintaining freshwater supply.
3. **Biomimetic Water Purification Systems**
   - Advanced filtration systems for buildings or neighborhoods, mimicking the natural filtration properties of mangrove roots to purify greywater or rainwater.

5. PINEAPPLE PEELS

Natural Model

The fibers in pineapple peels are highly absorbent, capable of soaking up water and holding it for long periods. These fibers naturally wick moisture, making them ideal for water retention in arid climates.



Figure 3.6. – Pineapple peels © SHVETS, pexels.com

Principle(s)

- Hydrophilic properties of lignocellulosic fibers
- Capillary action for water absorption
  - Capillary action can be defined as the ascension of liquids through slim tubes, cylinders or permeable substances due to adhesive and cohesive forces interacting between the liquid and the surface.
  - Moisture retention through natural fiber networks

AEC Translations(s)

1. **Water-Absorbent Facades**
   - Building exteriors made from natural materials inspired by pineapple fibers to absorb and retain moisture, improving passive water management in dry environments.
2. **Moisture-Buffering Building Insulation**
   - Non-mold producing insulation materials made from pineapple-derived fibers that absorb excess moisture during humid periods and release it when needed, helping to stabilize interior temperature and humidity.
3. **Rainwater Harvesting Systems**
   - Rainwater collection systems using pineapple fiber-based materials to absorb and store rainwater for later use in irrigation or cooling.

6. SPIDERS' SILK

Natural Model

Spiders' silk is highly water-repellent and extremely strong. The silk's microstructure allows it to capture moisture from the environment while remaining structurally intact, making it ideal for applications requiring both strength and moisture resistance.

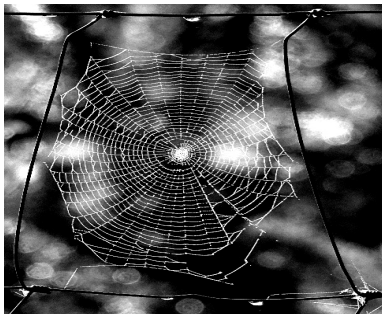


Figure 3.7. – Spiders' Silk © Jiří Mikoláš, Pexels.com

Principle(s)

- Water-resistant microstructure
- Tensile strength and flexibility
- Nano-scale surface hydrophobicity

AEC Translations(s)

1. **Water-Resistant Building Materials**
   - Advanced textiles or coatings for building exteriors inspired by spider silk's water resistance, providing superior weatherproofing and longevity to building materials.
2. **High-Strength, Lightweight Facades**
   - Spider silk-inspired materials for lightweight but structurally strong cladding systems that also prevent moisture infiltration, reducing energy demands for heating and cooling.

7. WORMS (EARTHWORMS)

Natural Model

Earthworms play a crucial role in maintaining soil moisture levels. Their burrowing activity allows water to infiltrate the soil more efficiently, while their bodies filter and redistribute nutrients and moisture within the soil.



Figure 3.8. –Worms © Hanniel Yaks , Pexels.com

Principle(s)

- Soil aeration and moisture distribution through burrowing
- Filtration and redistribution of nutrients and water
- Improved soil porosity for better water retention

AEC Translations(s)

1. **Soil Moisture Management Systems**
   - Landscape architecture that mimics earthworm activity by creating permeable surfaces and soil channels to enhance water infiltration and moisture retention in urban areas.
2. **Water Retention Green Roofs**
   - Green roofs inspired by earthworm burrows that facilitate water retention and filtration, allowing for better stormwater management in urban settings.
3. **Water-Absorbing Ground Covers**
   - Sustainable landscaping materials for ground covers or walkways that simulate the effects of earthworm burrows, improving water absorption and reducing runoff.

8. CORAL REEFS

Natural Model

Coral reefs act as natural water filters by trapping particles and promoting nutrient cycling within their ecosystems. The porous structure of corals allows water to flow through, while beneficial organisms within the coral structure filter out pollutants and enhance water quality.

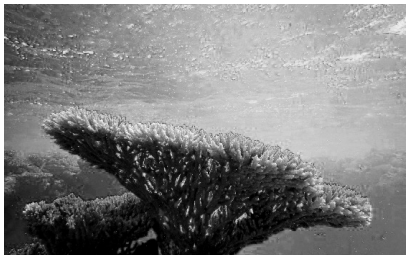


Figure 3.9. – Brown Coral Reef © Francesco Ungaro, Pexels.com

Principle(s)

- Porous, bioactive structures for water filtration
- Nutrient cycling within a complex ecosystem
- Increased water flow through porous architecture

AEC Translations(s)

1. **Bio-Active Water Filtration Systems**
   - Coral-inspired porous membranes or filtration units integrated into building façades or urban infrastructure that filter pollutants and improve water quality. This should be normalized in every downtown city, especially those over a certain population threshold.
2. **Self-Cleaning Water Features**
   - Architectural water features or ponds designed to mimic coral reef structures, enhancing water filtration while providing aesthetic and environmental benefits.
3. **Integrated Stormwater Management**
   - Urban rainwater management systems inspired by coral structures that filter and purify water before reusing it for irrigation or other purposes, improving water quality and reducing waste.

9. MOUNTAIN PINE BEETLE

Natural Model:

The Mountain Pine Beetle burrows into trees and creates pathways through the bark that guide sap flow to specific areas, increasing the moisture retention capacity of the tree.

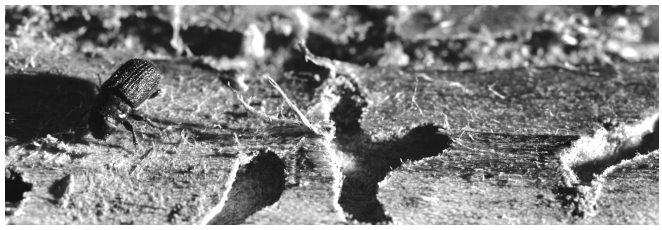


Figure 3.10. – Mountain Pine Beetle © csfs.colostate.edu

Principle(s):

- **Capillary action** within the beetle-carved channels increases moisture retention and water directionality.
- **Hydrophobic/hydrophilic gradients** allow water to flow efficiently through the tree's vascular system.

AEC Translations(s):

1. **Beetle-Inspired Water-Channeling Building Facades:**
   - Surfaces that mimic beetle pathways, capturing and channeling water to storage or cooling systems.
2. **Hydrophilic-Gradient Roofs:**
   - Roof structures that mimic beetle burrows, using capillary action to direct water from condensation into storage systems for reuse in arid climates.

Real-World Example:

- **Warka Water Towers** (Cameroon, Africa): These water-harvesting towers, akin to the mountain beetle, collect atmospheric moisture in arid and rural environments. The towers are designed to capture fog and dew, improving water collection in regions with limited rainfall.

10. CACTUS SPINES

Natural Model:

Cacti use their spines as a defense mechanism and to reduce water loss through transpiration. The spines serve as a solar shading system, blocking sunlight and creating localized air turbulence that reduces evaporation rates from the plant's surface.



Figure 3.11. – Cactus Spines © Lachlan Ross, Pexels.com

Principle(s):

- Localized air turbulence creates micro-climates around the cactus, reducing heat absorption and water loss.
- Spines as shade structures protect the plant while conserving water in extreme heat.

AEC Translations(s):

1. **Cactus-Inspired Shading Systems:**
   - Facade shading systems that mimic cactus spines, creating air turbulence to reduce solar heat gain.

2. **Desert Adapted Skin Layers:**
   - Building skins with embedded spine-like structures that reflect and diffuse sunlight while reducing heat absorption.

11. PANGOLIN SCALES

Natural Model:

The Pangolin is covered in tough, overlapping scales that provide protection against predators and harsh environmental conditions. The scales are arranged to allow flexibility while offering high impact resistance.



Figure 3.12. – Pangolin © Graeme Travers, Pexels.com

Principle(s):

- Flexible armor made of overlapping, interlocking scales absorbs and dissipates force.
- Self-adjusting armor that provides protection without compromising resilience.

AEC Translations(s):

1. **Pangolin-Inspired Protective Facades:**
   - Overlapping, flexible panels that absorb and distribute impacts from storms, seismic activity, or human interaction.
2. **Dynamic Building Skins:**
   - Flexible, impact-resistant surfaces that adjust based on external forces (e.g., wind, vibrations) for optimal building resilience.

Real-World Example:

- **Pangolin Pavilion** (*version of the pavilion was built in India by ANT Studio, refer to Figure 3.13.1*): A Pangolin-inspired façade that can be created using local materials to create clay tiles resembling the scales of a pangolin.



Figure 3.13. – Pangolin Pavilion © Valerie Schweitzer Architects



Figure 3.13.1. – Pangolin Pavilion in India © Jaidev, ANT Studio

"Installed at the School of Planning and Architecture in Delhi, the Pangolin Pavilion was created with a two-pronged motive – to educate young architects and students about the concept of Parametricism and to draw attention to the widespread poaching of Pangolins, the most trafficked mammals in the world..."
– Home & Design TRENDS

12. MIMOSA PUDICA (SENSITIVE PLANT)

Natural Model:

The Mimosa Pudica plant adjusts its leaves in response to environmental stimuli, such as touch or sunlight, by altering the *turgor pressure* in its cells.

This allows the plant to optimize energy absorption and conserve resources.



Figure 3.14. – Mimosa Pudica © TheSpruce.com

"...What is turgor pressure?

In a biological context, turgor pressure is the pressure that is exerted by water on the wall of a cell. Think of a balloon that is being filled up with water as a turgor pressure example. The balloon swells as more water draws in. The pressure that the water exerts against the walls of the balloon is similar to the turgor pressure exerted against the wall..." **– Biology Online**

Principle(s):

- Turgor-driven response to environmental stimuli causes rapid leaf movement.
- Self-adjusting systems that can react to changes in light intensity or temperature.

AEC Translations(s):

1. **Self-Adjusting Solar Panels:**
   - Panels that adjust their angle based on sunlight intensity to maximize energy capture, inspired by the plant's leaf movement.
2. **Adaptive Shading Facades:**
   - Mimosa-inspired facades that open or close based on sunlight, wind, or temperature conditions, reducing solar heat gain while optimizing natural daylight.

Real-World Example(s):

- **The Bosco Verticale (Vertical Forest)** (Milan, Italy): The facades of the towers feature plants that respond dynamically to environmental conditions, thus improving thermal comfort, air quality, and energy efficiency.



Figure 3.15. – Bosco Verticale, Milano, Italia © pedestal-eternoivica.com

- **UTS Central Building** (Sydney, Australia): Features a "living" shading system that uses solar-tracking to optimize and regulate daylight intake as needed for occupant comfort and to reduce energy consumption for cooling.



Figure 3.16. – UTS Central Building, Sydney, Australia
© Tilt-IndustrialDesign.com

"…A series of intricate, operable sun shades that integrate seamlessly into the north-facing façade of the building and move to adjust the amount of light and heat. The combination of fixed and operable louvres provides dual functionality, controlled via an optimised algorithm based on the sun's position throughout the day. This intuitive technology helps to regulate the sun streaming into the central Reading Room, providing greater comfort for staff and students…" – Tilt Industrial Design

Additional Natural Organisms you can research on your lunch break

ORGANISM	KEY PRINCIPLE	BUILDING TECHNIQUE	PRIMARY BENEFIT
NAMIB BEETLE	Hydrophilic/ hydrophobic patterning	Fog/dew-harvesting exterior surfaces	Passive water supply in arid zones
GECKO FEET	Reversible dry adhesion	Temporary cladding	Damage-free installation/removal
MORPHO WINGS	Structural color + directional water repellency	Iridescent glazing, scaled roofing	Passive solar control + water shedding

PART 3 – BIOMIMICRY IN MATERIAL SCIENCE AND WATER MANAGEMENT | KNOWLEDGE CHECK (5 QUESTIONS)

1. **What is the primary mechanism behind the self-cleaning property of the Lotus Leaf?**
   A. Hydrophilic surface that absorbs water
   B. Superhydrophobic surface with a unique micro/ nano texture
   C. Capillary action that traps water droplets
   D. Hygroscopic movement driven by humidity

2. **How does shark skin inspire anti-fouling finishes in architecture?**
   A. By using hydrophilic properties to attract water
   B. By mimicking riblets that reduce drag and prevent bacterial settlement
   C. By creating a porous structure for water absorption
   D. By using capillary action to filter water

3. **What principle of pinecones is applied in responsive cladding systems?**
   A. Superhydrophobic surface for water repellency
   B. Hygroscopic movement driven by moisture changes
   C. Riblets for drag reduction
   D. Turgor-driven response to environmental stimuli

4. **How do mangrove roots inspire water filtration systems in architecture?**
   A. By using ribbed frameworks for structural strength
   B. By filtering saltwater through specialized root structures
   C. By creating superhydrophobic surfaces for water repellency
   D. By using capillary action to absorb and retain water

5. **What is the key feature of spider silk that inspires water-resistant building materials?**
   A. Hydrophilic surface for water absorption
   B. Nano-scale surface hydrophobicity and tensile strength
   C. Hygroscopic movement for moisture retention;
   D. Capillary action for water dispersion;

This concludes Part 3 of the course.

Let's continue to Part 4.

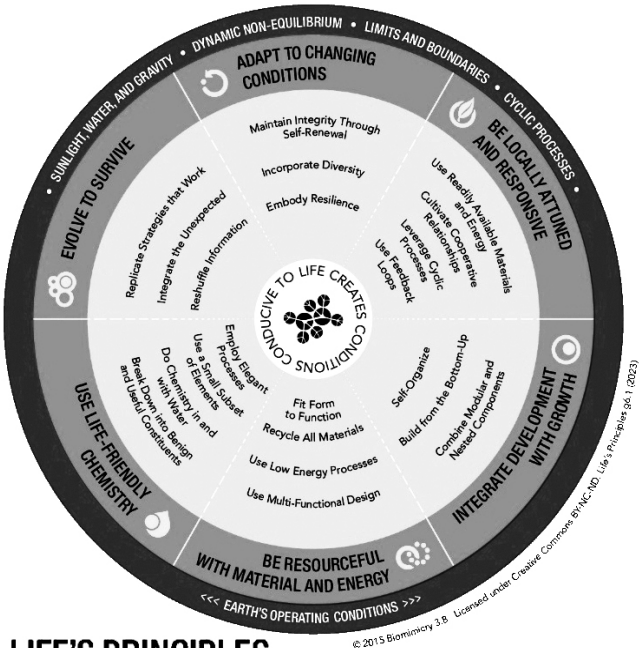
PART 4 – REAL WORLD EXAMPLES OF INTEGRATED BIOMIMETIC STRATEGY AND REGENERATIVE PERFORMANCE IN THE BUILT ENVIRONMENT

Learning Objective No. 4: Identify and Understand buildings with integrated biomimetic strategy and regenerative performance.



These natural systems inspire advanced, innovative materials and architectural solutions that optimize water management, surface functionality, and sustainability.

By integrating these biomimetic designs, buildings and urban environments are more adaptive, energy-efficient, and responsive to climate challenges; A huge issue currently and for the foreseeable future.



LIFE'S PRINCIPLES
Biomimicry DesignLens
Biomimicry.net

Figure 4.1. – Life's Principles © biomimicry.net

You will find below, buildings that function like healthy ecosystems, actively healing and enriching the environment versus being "sustainable" i.e. minimizing the damage they do to the environment.

As we have repeated numerous times, these buildings emulate or parallel nature's cyclical processes i.e. purifying air/water, producing food/energy, and adapting to change.

REAL-WORLD AEC EXAMPLES OF BIOMIMICRY AND ITS LIFE'S PRINCIPLES IN ACTION

Building: Al Bahar Towers (LEED Silver)

Biomimicry Life's Principle Applied: Adapt to changing conditions



Figure 4.2. – Al Bahar Towers, Abu Dhabi, UAE
© Christian Richters, chi-athenaeum.org)

Architect: Aedas Architects (now AHR)

Location: Abu Dhabi, UAE

How?: Computer-controlled mashrabiya screens* open/close daily with sun position

**Mashrabiya screens are intricate, latticed wooden screens common in African/Asian architecture, used for privacy, shade, and ventilation, creating beautiful patterns of light indoors while allowing occupants to see out without being seen.*

"…The building facade is the modern interpretation of mashrabiya that transformed into a dynamic facade system comprising over 2,098 umbrella-like shading devices. Each element opens and closes in response to the sun's position, creating a building envelope that breathes with the desert heat. The skin of the Al Bahar Towers was developed using parametric and computational design tools…" – Parametric-Architecture

The high rises (+/- 475'-0") with a combined square footage of +/- 559,723 GSF were designed specifically with the UAE's hot desert climate ("BWh" per the Köppen system) in mind. The mashrabiya screens are comprised of 2,098 of the flower shaped responsive elements which allow the façade to respond to the diurnal (daily) cycle of the sun in real time.

Here is a great video on how the screens work and a mention is made of the reduced energy consumption which ties into the solar heat gain which is reduced amazingly by more than 50%! The occupancy classification of both high rises are business occupancy classifications and thus with this design it affords everyone access to sunlight which has been proven time and time again to elevate one's mood and improve productivity.

"…Workers in windowless environments reported poorer scores than their counterparts on two SF-36 dimensions–role limitation due to physical problems and vitality–as well as poorer overall sleep… Compared to the group without windows, workers with windows at the workplace had more light exposure during the workweek, a trend toward more physical activity, and longer sleep duration as measured by actigraphy.

Conclusions: We suggest that architectural design of office environments should place more emphasis on sufficient daylight exposure of the workers in order to promote office workers' health and well-being…" – PMC NCBI NIH.gov

Honestly every building should have a similar narrative no matter where it is located.

Building: Khoo Teck Puat Hospital (KTPH) aka "the Hospital in a Garden"

Biomimicry Life's Principle Applied: Be locally attuned and responsive



Figure 4.3. – Khoo Teck Puat Hospital,Yishun, Singapore
© living-future.org)

Architect: Collaboration between CPG Consultants Pte Ltd (the executive architect) and RMJM Hillier (the design consultant)

Location: Yishun (formerly Nee Soon), Singapore

How?: The entire hospital was designed with only the local tropical climate, native plants, and Singapore's rainfall patterns in mind. The design reduces energy consumption drastically and has the option to be naturally ventilated.

As you can see from the image *(refer to Figure 4.3, page left)* and quote below, biophilic design and biomimicry are combined, biophilic design is very important and even moreso in healthcare settings when people are not feeling their best or are fighting hard to recover from an illness.

"Yishun Pond itself grew to be a central feature of the design; inpatient units face the pond, whose shoreline is to be reclaimed for exercise paths and food pavilions.

The pond provides a soothing waterscape view for staff and patients in the nursing towers at the eastern edge of the 32,000 sqm site,

while the garden landscape greets visitors, patients and staff at the entry to Yishun Central Avenue at the western extremity. A series of planted terraces between upper floor patient towers culminate the "garden hospital" experience." – RMJM

Another amazing "green" fact is that the total surface area of the horizontal and vertical greenery is close to 4x the size of the lot the hospital is placed on. Aside from incorporating an existing pond (Yishun Pond) into its design which increased visitors and promoted health and fitness (they added a walking trail around the pond that linked to other businesses and residential areas, they also only used local plant life which in turn brought local animals and creatures native to the area. More specifically, over 83 butterfly species have been observed on hospital grounds. It is said a butterfly represents the soul of a deceased family member or loved one visiting you from the afterlife.

Now imagine being in the hospital by yourself and you see numerous butterflies outside of your patient suite, you will know that you have the support of your loved ones that have passed on. This will add to your resolve and strength to fight whatever you are fighting or to accept your fate and rest assured that you will soon be a with your family and a "butterfly" as well.

Building: Bullitt Center

Biomimicry Life's Principle Applied: Use life-friendly chemistry



Figure 4.4. – Bullitt Center, Seattle, WA, USA © bullittcenter.org

Architect: Miller Hull Partnership

Location: Seattle, Washington, USA

How?: The building excludes 362 "Red List" elements that are toxic, carcinogenic, mutagenic, or endocrine disrupting, this includes materials and furnishings as well. The list is produced by the International Living Future Institute (ILFI).

The building also has a rainwater collection and filtering system, on-site treatment of sewage, and composting toilets.

The Bullitt Center also became the first office in the United States to receive a project certification from the Forest Stewardship Council. Here is a great article on the Bullitt Center.

Building: The Edge

Biomimicry Life's Principle Applied: Be resource efficient



Figure 4.5. – The Edge, Amsterdam, The Netherlands © bloomberg.com

Architect: PLP Architecture with local support from OeverZaaijer as architect of record (AOR)

Location: Amsterdam, The Netherlands

How?: By being extremely efficient and generating more energy than it consumes. The building utilizes solar panels, rainwater harvesting system, et. cetera to support its integrated, digitized energy network that uses smart meters to manage and optimize the production, distribution, and consumption of energy including renewable sources. The building has sensor-controlled lighting and heating and reduces carbon emissions. From the beginning the building was designed to be "energy-positive", which means as we stated before – the building generates more energy than it consumes.

"…Regarded as one of the world's greenest office buildings, The Edge achieved a BREEAM Outstanding rating with a record-breaking 98.36 percent score…" – Institute of Sustainability Studies

Building: Centre for Science and for Children aka The "Cradle-to-Cradle Pavilion" aka Terra – The Sustainability Pavilion

Biomimicry Life's Principle Applied: Break down into benign constituents



Figure 4.6. – The "Cradle-to-Cradle Pavilion" aka Sustainability Pavilion (Terra), Jebel Ali, UAE © construction21.org

Architect: Grimshaw

Location: Jebel Ali, UAE

How?: All materials certified Cradle-to-Cradle; Captures solar energy and water from the air, utilizes recycled products in some of its functions, and focuses on a closed loop system where all waste is repurposed to something useful for a new cycle. For example, the project utilizes carpet tiles that are compostable and can be returned to the soil.

"…Drawing inspiration from complex natural processes like photosynthesis, the dynamic form of the Pavilion is in service to its function, capturing energy from sunlight and fresh water from humid air…" – Grimshaw

TERRA – THE SUSTAINABILITY PAVILION EXPO 2020 DUBAI: CASE STUDY

This project made great use of local resources from placing an emphasis on the subsurface where the heat in the warmer months can not cause occupant discomfort.

What happens with those spaces above ground?



Figure 4.7. – Image of a Gabion wall veneer © gabionsupply.com

There is an earth roof system, which reduces the cooling load for the active system servicing the building.

The use of a light-colored gabion rainscreen wall comprised of local stone from the mountains nearby that acts as a thermal mass to absorb heat and reflect the sun. The same was done regarding the landscaping (flora and fauna) which interestingly enough included species never cultivated by humans. Water recycling and reuse occurs on-site as well.

"…Soaring over the courtyard, the Pavilion's canopy accommodates more than 6,000 sqm of ultraefficient monocrystalline photovoltaic cells embedded in glass panels. The combination of the cell and the glass casing allow the building to harness solar energy while providing shade and daylighting to the visitors below…"
– Grimshaw

Building: Park 20|20

Biomimicry Life's Principle Applied: Use cyclical processes

Architect: William McDonough + Partners, Master Planning

Nelson Byrd Woltz, Landscape Architect

Location: Beukenhorst Zuid, Hoofddorp, Haarlemmermeer, North Holland, the Netherlands

- **How?:** Modeled after natural nutrient cycles and creates "closed-loop" systems to sustainably manage waste, energy, and water.

"90% reductions in water use via the development's solar-powered grey-water treatment facility." – Healthy Urbanism

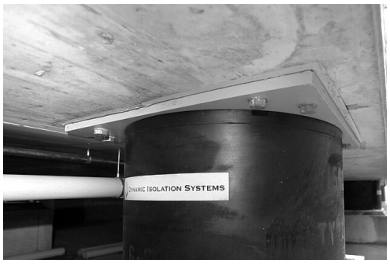


Figure 4.8. – Park 20|20 is the first Cradle-to-Cradle (C2C) urban development project in the Netherlands (in Hoofddorp) © healthyurbanism.net

"Responding to its unique cultural, environmental and contextual challenges, the…Park 20|20 master plan creates a mixed-use development that synthesizes the issues of access and mobility, connectivity, passive design, and integrated energy, water and waste management systems…"
— William McDonough + Partners

Building: Venlo City Hall (stadskantoor (council offices))

Biomimicry Life's Principle Applied: Recycle all materials



Figure 4.9. – Venlo City Hall, Venlo, Netherlands © inhabitat.com

Architect:

Location: Venlo, Netherlands

How?: 99.8 % construction waste diverted + material passport for future disassembly

"Two solar chimneys also passively heat and cool the building."
– Ellenmacarthurfoundation.org

The "…top floor features a greenhouse with seasonal workplaces and room to grow regional products that also heats and humidifies the air that enters the building.

The green air-purifying façade is the largest green building façade in the world and forms a protective shell against traffic and railway pollution…" **– Kraaijvanger**

The building purifies air through the 'green lung' façade, recycles rainwater and waste water, is energy neutral and promotes wellbeing. In addition, the building produces no waste: it is in fact a temporary raw materials bank with guaranteed residual values for a number of products. The building's green façade creates (bio)diversity: like a vertical city park, it is a natural biotope for more than 100 plants, animals and insect species.

The air in Venlo's new city hall is purer than the air outside and purifies air in a 500m radius around the building. Cradle to cradle principles and holistic thinking in action in a city's buildings.
– Ellen MacArthur Foundation

Aside from your typical city hall programming there is also a lush garden with helophyte filters.

Helophyte filters are natural, earth friendly water purification systems that use wetland plants (for example reeds) and their root systems, along with filtering media (sand or gravel) and beneficial bacteria, to remove pollutants like nitrates, phosphates, and organic matter from wastewater or runoff.

There are two types of helophyte filters, up-flow and down-flow, up-flow is the better filter if your client can afford it.

HELOPHYTE (NATURAL WATER PURIFICATION SYSTEM) FILTER TYPES
(Quantities, diameter and lengths vary per project)

UP – FLOW	DOWN – FLOW
Required materials Up-flow:	Required materials Down-flow:
A Wall duct.	A Drain collector.
B Grid with vegetation mat.	B PE drainage pipe with sockets.
D Clean lava or pond substrate.	C Bio balls or Zeolite.
D Bio balls or Zeolite.	D Clean lava or pond substrate.
E Emergency shaft.	E PVC pipe.
	F Wall ducts
Features of Up-flow filtration	Down-flow filtration features
– Excellent contamination management.	– Lower technical cost.
– Lower impact on the substrate bed.	– Higher maintenance frequency.
– Lower maintenance frequency.	– More bottom contamination.
– Pre-filtration possible.	– Pre-filtration is not possible with this construction.
– Higher fitting costs.	

Source: https://tinyurl.com/2zsry5mc

Building: Eastgate Centre

Biomimicry Life's Principle Applied: Leverage cyclic processes

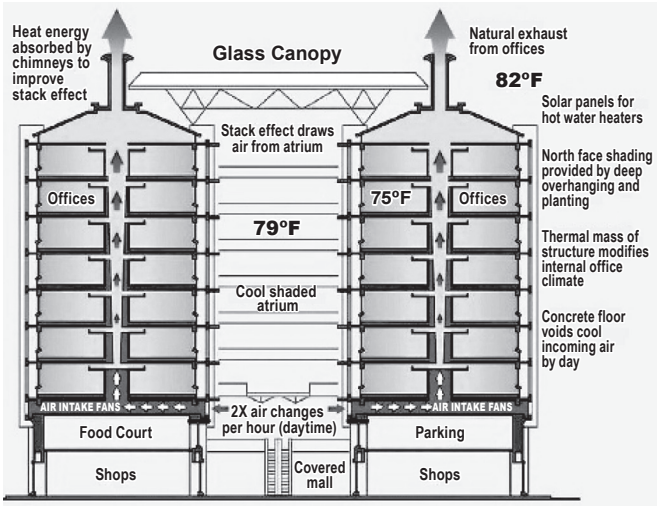


Figure 4.10. – Eastgate Centre, Harare © neverenougharchitecture.com

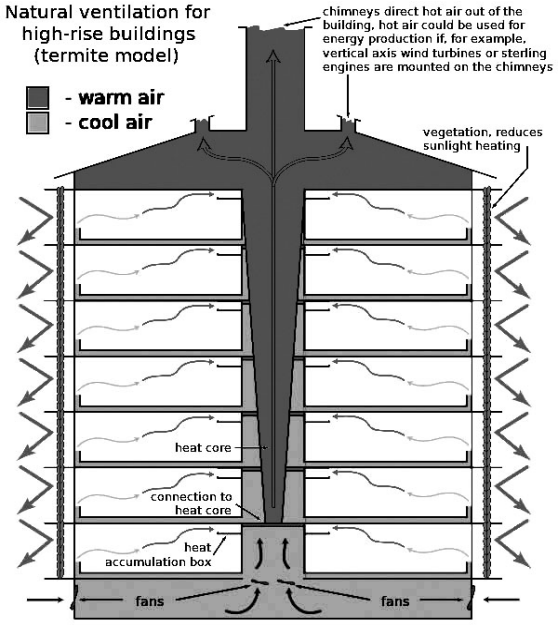


Figure 4.11. – A schematic showing the natural ventilation used in the Eastgate building in Harare. © AskNature.org

Architect: Mick Pearce in collaboration with Arup engineers (Enjoy this really great podcast with Mick Pearce)

Location: Harare, Zimbabwe, Afrika

How?: Uses passive systems and energy-efficient mechanisms to maintain occupant comfort and reduce energy consumption. The true definition of biomimicry as its natural ventilation system mimics indigenous Zimbabwean masonry mastery and self-cooling termite mounds as mentioned in earlier sections.

> **"…the $35 million building saved 10% on costs up-front by not purchasing an air-conditioning system. Rents are less expensive in this building compared to nearby buildings because of the savings in energy costs…" – AskNature.org**

The building has no conventional air conditioning or heating but has an interior temperature that stays regulated year-round.

"Outside air that is drawn in is either warmed or cooled by the building mass depending on which is hotter, the building concrete or the air. It is then vented into the building's floors and offices before exiting via chimneys at the top. The complex also consists of two buildings side by side that are separated by an open space that is covered by glass and open to the local breezes." – Inhabitat.com

Building: BIQ (Bio Intelligent Quotient) House

Biomimicry Life's Principle Applied: Use multifunctional design

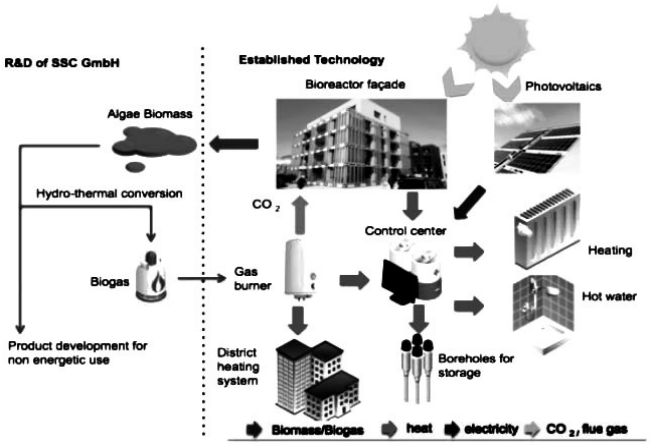


Figure 4.12. – BIQ House algae façade, Hamburg, Germany © Steemit

Architect:

Location: Hamburg, Germany

How?: This was the world's first pilot project to showcase a bioreactive façade and the world's first algae-powered building.

How is it bioreactive? Multifunctional?

Over 2K square footage of integrated photo-bioreactors, which generates biomass and heat as renewable energy resources.

Simultaneously the building also has dynamic shading, thermal insulation and noise abatement. The noise abatement plays well into the typology of the 4 storey building which houses 15 residential units.

> **"The microalgae used in the facades are cultivated in flat panel glass bioreactors measuring 2,5m x 0,7m. In total, 129 bioreactors have been installed on the south west and south east faces of the four-storey residential building. The heart of the system is the fully automated energy management centre where solar thermal heat and algae are harvested in a closed loop to be stored and used to generate hot water." – Architonic**

The bioreactors are placed to harvest the sunlight on all sun-facing sides of the building which the algae use as fuel to initiate its photosynthesis process and generate bioenergy.

What is even cooler (no pun intended) is that each bioreactor panel can rotate on its vertical axis to track the sun path and then in the evening close and act as a thermal buffer.

There are a total of 129 bioreactors (which contain 6 gallons of water each) which produce an annual net energy output of 4.5K kWH exceeding the average household at 3.5K kWh. This means even more given this is a residential building.

What is interesting is that there is some continuous maintenance required – compressed air injections done periodically to optimize algae growth *and* prevent overaccumulation. What truly ensures the algae growth and nourishment is carbon dioxide (algae's main food source) it is supplied from the exhaust of a ground-floor generator.

"…excess heat produced by the algae-filled panels is harnessed and used to improve the building's overall energy efficiency. This heat is transferred to a heat exchanger and either used directly for domestic hot water and space heating or stored in saline water tanks beneath the building for later use. By repurposing the heat generated within the bioreactors, the BIQ House maximises (sic) energy savings and further demonstrates how living systems can contribute to sustainable architectural solutions…"
– Re-Thinking The Future

Not really a maintenance item but something that must be planned and maintained – the algae is harvested weekly and transported to a nearby university for processing into methane and hydrogen.

Can this be adopted worldwide?

Yes and no. The BIQ House is successful almost exclusively based on its geographic location and climate.

Hamburg, Germany is located on the Elbe River where it meets the Alster and Bille rivers and has a temperate Oceanic Climate i.e. moderate temperatures, no dry season, and warm summers ("Cfb" in the Köppen classification system). Where a replica of the BIQ house would be most successful is the following locations that have a similar geographic location and climate:

North America
- Port Angeles, Washington, USA
- Victoria, British Columbia, Canada

South America
- Valdivia, Chile
- Curitiba, Brazil

Oceania
- Melbourne, Australia
- Auckland, New Zealand

Africa
- George, South Africa
- Dullstroom, South Africa

Asia
- Matsue, Japan
- Da Lat, Vietnam

Europe
- Amsterdam, Netherlands
- London, United Kingdom

If you are stateside or really smitten with bio-reactive facades and the like you will be glad to know that the University of North Carolina – Charlotte in Charlotte, North Carolina received a grant from the National Science Foundation to fund the development of a high-performing window system that "…reduces building energy consumption and carbon dioxide emissions…"

– Inside UNC Charlotte

Building: Basílica de la Sagrada Família

Biomimicry Life's Principle Applied: Fit form to function



Figure 4.13. – Basílica de la Sagrada Família columns, Barcelona, Spain
© wandering-through-time-and-place.com

Architect: Antoni Gaudi

Location: Barcelona, Spain

How?: Tree-branching, bone-inspired hyperboloid columns carry load with minimal material. Antoni drew his inspiration directly from nature.

"The interior pillars resemble trees and, when looking up, the shapes of the pillars change as do those of the trees. Gaudí designed images of a turtle and tortoise on these pillars to represent the water and earth."
– Catalonia Hotels

Gaudi was true to himself and to the world. His beliefs and love of nature shone through in all of his works, one example of many being Basílica de la Sagrada Família. As Gaudí said "*This tree by my workshop, this is my master!*"

"…Gaudi had his own unique source, and that made him special and different from other artists/architects.

It was NATURE – he loved nature…In addition, when he was sick in early ages, nature was his best friend – he observed nature everyday and inspired by it.

The nature easily became his strength and specialty as an artist. There is none of his artworks that are not related to the nature. Nature was his artistic motivation and the most significant material. It soon became his own artistic identity and storytelling.

Everything in his architecture is based on NATURE…"
– So Sunny Project

Building: Powerhouse Kjørbo

Biomimicry Life's Principle Applied: Use only the energy needed



Figure 4.14. – Powerhouse Kjørbo, Norway © kommunikasjon.ntb.no

Architect: International architecture firm Snøhetta, Swedish contractor Skanska, the environmental NGO Zero, and various other partners

Location: Sandvika, Norway

How?: "Powerhouse Kjørbo, which is Norway's first energy-positive office building and may be the first renovated energy-positive building in the world" – Business Norway

To support making the renovation a success in the direction of being energy-positive, the existing façade was replaced with triple-glazing and insulated panels and certain existing windows repurposed with interior partitions.

"…During construction, we prioritized recycling and reusing materials, resulting in over 90% of construction waste finding new life in other projects…"
– Rise Design Studio

The existing roof was bolstered and modified to house over 16K square feet of solar photovoltaic arrays which produce 2x the energy the building needs to function.

This project also received (based on BREEAM-NOR, passive house standard NS 3701) an environmental classification of BREEAM-NOR Outstanding.

This project alone proves that with the right leadership and backing any existing building can go from blight to game changer overnight.

Building: Gando Primary School

Biomimicry Life's Principle Applied: Self-organize



Figure 4.15. – Students sitting in the shade of Gando Primary School, Gando, Burkina Faso, Afrika © Erik-Jan Ouwerkerk, kerearchitecture.com

Architect: Francis Kéré of Kéré Architecture

Location: Gando, Burkina Faso, Afrika

How?: Local communities self-build with modular clay blocks that evolve over time.

Local materials and resources near the site were used to construct the school including clay bricks as mentioned above but also a clay/cement hybrid brick.

Where the bricks were strong and acted as a thermal barrier they needed to be protected from the rain which damaged its composition.

The building has no need for an active system to provide HVAC as the entire school is naturally ventilated. The corrugated metal roofing system paired with a clay brick roof/ceiling and cool air coming in from interior windows supports the need for only natural ventilation.

> **"…For this project, traditional building techniques and modern engineering methods were combined to produce the best quality building solution while simplifying construction and future maintenance. The success of the project can be attributed to the close involvement of the local population in the building process…" – Kere Architecture**

Building: Earthship Biotecture

Biomimicry Life's Principle Applied: Use low-energy processes



Figure 4.16. – Earthships (global) made of tire walls © nbcnews

Architect: Michael E. Reynolds

Location: Worldwide

How?: "An Earthship is a style of architecture developed in the late 20th century to early 21st century by architect Michael Reynolds. Earthships are designed to behave as passive solar earth shelters made of both natural and upcycled materials such as earth-packed tires." – Wikipedia

This type of architecture is two-fold as it does use every day discarded items to build housing but unfortunately it did not resolve standard issues traditional houses never face or never face consistently which are leaky roofs or inadequate climate control i.e. poor occupant comfort.

If you have time on a Saturday night when you are not transforming the AEC industry, watch "Garbage Warrior" which tells the story of eco architect Michael E. Reynolds.

Building: 3D Printed Stainless Steel Pedestrian Bridge

Biomimicry Life's Principle Applied: Use benign manufacturing



Figure 4.17. – MX3D 3D-printed steel bridge, Amsterdam (2021) © friedmanbenda.com)

Architect: MX3D; Joris Laarman Lab and engineered by Arup. Additional expertise was provided by ArcelorMittal, Autodesk, Heijmans, Lenovo, ABB, Air Liquide & Oerlikon, Plymovent, and TU Delft

Location: Amsterdam, the Netherlands

How?: Building a bridge using 3D printing which required 50% less steel, generated zero formwork waste, and cost savings up to 80%.

What is interesting is that such a forward-thinking bridge was used to cross "…one of the oldest and most famous canals in the center of Amsterdam…".

There is a sensor network on the bridge that collect structural measurements (like strain, displacement, and vibration) and measures environmental factors like air quality and temperature. This permits engineers to measure the bridge's structural health in real time and monitor how it changes over its lifespan.

Interested in bringing a 3D printed bridge to your jurisdiction? Here is the reality:

> **"…Building a 3D-printed bridge in Amsterdam's Bridge District involves relatively high upfront costs, a multi-year timeline, and careful regulatory coordination. The project required significant investment in robotic 3D-printing technology, stainless-steel materials, engineering expertise, testing, and digital monitoring systems, making it more expensive than a conventional small pedestrian bridge at this experimental stage.**
>
> **The timeline extended over several years: the design and technology development started around 2015, the robotic printing itself took several months, and additional time was needed for structural testing, sensor integration, and approvals before the bridge was installed and opened to the public in 2021…" – MX3D**

Building: Bosco Verticale (residential towers)

Biomimicry Life's Principle Applied: Build resilience through diversity



Figure 4.18. – Bosco Verticale, Milano, Italia © pedestal-eternoivica.com

Architect: Stefano Boeri

Location: Porta Nuova District, Milano, Italia

How?: This project embodies biodiversity due to having 900 trees, 1000s of plant species and shrubs. All of which attract local animal species and contribute to acting as a buffer to the wind.

What is interesting also is that landscaping was meticulously selected based on specific needs in terms of exposure, for example evergreens were placed on the southwest side and deciduous trees on the northeast side. With this their height development in relation to balcony design, and their impact on occupant health and well-being. You can see the strong biophilic design elements in this project as well. We know it will be greatly appreciated by the building occupants and their visitors.

Speaking of occupants, each apartment contains at least 2 trees, 8 shrubs, and 40 plants for each tenant, allowing for proximity to the green component and the related physical and psychological benefits. Again, the biophilic design aspect is coming into play.

In addition, there is a water management system that utilizes groundwater and recycles the building's greywater. On the roof, solar panels provide the energy required to pump water to all floors through the irrigation system for the plants.

> **"…The Bosco Verticale houses vegetation equivalent to about five hectares of parkland on flat land, but concentrated on an area of approximately 1,000 square meters, which is fifty times less.**
>
> **It offers significant benefits in terms of fine dust and CO2 absorption, oxygen production, optimization of water management, reduction of noise pollution, and improvement of the life quality–for humans, plants, and animals…" – Stefano Boeri Architetti**

Building: Oman Botanic Garden

Biomimicry Life's Principle Applied: Create conditions conducive to life



Figure 4.19. – Oman Botanic Garden, Al Hajar Mountains, Oman © inhabitat.com

Architect: Grimshaw Architects

Location: Al Hajar Mountains, Oman

How?: Restores degraded wādī *(which means valley or dry riverbed)* ecosystem while housing the building; net-positive water & biodiversity.

Botanic diversity is shown in this project by the two biomes and surrounding external habitats which contain the country's most endangered and endemic flora.

> **The garden contains "…Passive and active shading, UV light controls, cooling and plant irrigation are integrated throughout the gardens. Building form, shape and materials have been considered and selected in response to atmospheric conditions and the natural topography…" – Grimshaw**

Building: Pixel Building

Biomimicry Life's Principle Applied: Optimize rather than maximize



Figure 4.20. – Pixel Building, Melbourne, Australia © inhabitat.com

Architect: Studio 505; Developer was Grocon

Location: Melbourne, Australia

How?: Along with being "Australia's First Carbon Neutral Building" – inhabitat.com.

This project generates its own power, practices on-site rainwater harvesting, waste reduction, is energy efficient, utilizes wind turbines, solar panels, and green roofs.

As expected with traits as those stated above, this project has earned a top Green Star rating and LEED rating.

> **"…Pixel has achieved a perfect score of 100 under the Greenstar rating system, with 75 points the benchmark for 6 Star Greenstar. It gained an extra five points for innovation, equating to world leadership. Included in Pixel's five innovation points were points for carbon neutrality, a vacuum toilet system, the anaerobic digestion system and reduced car parking…" – Studio 505**

Building: Masdar City wind towers & solar chimney

Biomimicry Life's Principle Applied: Use free energy



Figure 4.21. – Masdar City wind towers & solar chimney prototypes © solarchitecture.ch

Architect: Foster + Partners provided the sustainable vision and integrated the passive cooling/energy systems in the city's design

Location: Masdar City, Abu Dhabi, UAE

How?: Provides cooling by use of an ancient wind tower (or barjeel), which captures the prevailing wind, channels it down past cooling mist jets into a central courtyard.

Also this is the first building of its kind to be powered entirely by renewable solar energy.

> **"A 10-megawatt solar field within the masterplan site provides 60 per cent more energy than is consumed by the Masdar Institute, all of which can be fed back to the Abu Dhabi grid." – Foster and Partners**

Building: CH2 – Council House 2

Biomimicry Life's Principle Applied: Cross-pollinate & collaborate



Figure 4.22. – CH2 – Council House 2, Melbourne © inhabitat.com

Architect: Mick Pearce

Location: Melbourne, Australia

How?: Deep collaboration between all stakeholders and end users i.e. biologists, engineers, artists, and citizens from day one as the building was "…examined and rethought from first principles, evolving new precepts that are based in the desire to be as true as possible to the fundamental "laws of nature...".

Interesting energy and architectural facts:

Power consumption is 80% reduced, water consumption is 75 reduced, air intake is not recycled at all (100% filtered outside air), biophilic interior, non-toxic materials, a roof garden, and a plant-to-person ratio of 1.

> **"…the first in the country to achieve the highest possible rating of six stars in Australia's Green Star environmental accreditation… CH2's public face is the tall facade overlooking Swanston Street, one of Melbourne's public boulevards. It is entirely composed of timber vertical slats covering a fully glazed wall. These slats pivot vertically, opening and closing in response to the time of day and the angle of the sun.**
>
> **The facade is thus animated in direct response to the external conditions. This is biomimicry at its very best – the building moving and becoming alive in response to the conditions surrounding it…" – Mick Pearce**

Building: ETH Zurich Block Research Group

Biomimicry Life's Principle Applied: Build from the bottom up



Figure 4.23. – Nacre-inspired concrete panels, ETH Zurich Block Research Group © Ethz.ch)

Architect: *ETH Zurich Block Research Group*

Location: Zurich, Switzerland

How?: "Researchers at ETH Zurich's Department of Architecture (D-ARCH) have developed a concrete floor system that does not require steel reinforcement and is 70 percent lighter than conventional concrete floors. Their design was inspired by historical construction principles." – Ethz.ch

Building: WikiHouse

Biomimicry Life's Principle Applied: Combine modular & nested components

Architect: Alastair Parvin and Nicholas Ierodiaconou (Nick Ierodiaconou) as part of the London design practice 00 (Zero Zero)

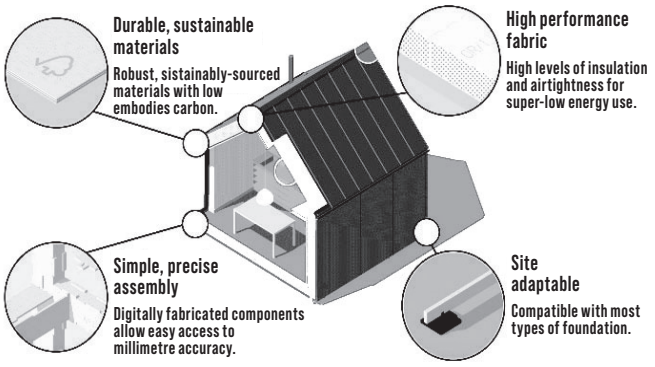


Figure 4.24. – WikiHouse open-source system (global deployments) © architizer.com

Location: Global

How?: By giving all people the ability to use a modular system to create a beautiful, high-performance, energy efficient, zero-carbon home.

"Free: Download a Construction Kit to Build Your Own "WikiHouse" This open-source construction kit can be turned into a home in just one day." – architizer.com

> **"Advanced building technology, for everyone. WikiHouse uses digital fabrication to create timber building components that can be assembled in hours, to millimetre precision. We have a growing network of engineers, manufacturers and installers who can help you build your project better, faster." – Wikihouse**

Building: Netherlands

Biomimicry Life's Principle Applied: Foster self-renewal & regeneration



Figure 4.25. – Sand Motor peninsula + Building with Nature, Netherlands Coast © climate-adapt.eea.europa.eu

Architect: Collaboration project led by H+N+S Landschapsarchitecten, involving Deltares and DHV, with construction by Boskalis and Van Oord

Location: Netherlands Coast

How?: Sediment is continuously renewed by wave action along the coastline.

> **"With the Sand Motor pilot project, a large quantity of sand was deposited near the Dutch coast. Wind, waves and sea currents gradually distribute the sand along the coastline between Hook of Holland and Scheveningen." – H+N+S**

These projects collectively prove that Biomimicrys' Life's Principles are already achievable today with existing technology and materials– no excuses. Regenerative, biomimetic, Living Building-level performance is not theoretical– it's built and tangible. We purposely did not show the dates but some of these projects are almost 20 years old.

Let's take a closer look at what could be considered in the USA as the definition of Biomimicry or as some even call it the World's Greenest Commercial Building.

The Bullitt Center (Seattle, Washington, USA)



Figure 4.26. – The Bullitt Center – Exterior View © bullittcenter.org

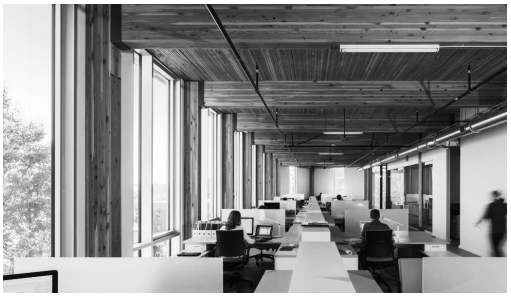


Figure 4.27. – The Bullitt Center – Interior View © bullittcenter.org



Figure 4.28. – The Bullitt Center – Interior Office View © lloydalter.substack.com



Figure 4.29. – The Bullitt Center – Lobby © bullittcenter.org

BIOMIMETIC STRATEGY / NATURAL MODEL	HOW THE BULLITT CENTER TRANSLATES IT	LIFE'S PRINCIPLE(S) EMBODIED	PERFORMANCE OUTCOME
FOREST AS THE ARCHETYPE (ECOSYSTEM-LEVEL BENCHMARK)	Reduction of the carbon footprint due to the FSC-Certified heavy timber structure. The timber was sourced locally within 621 miles from the project site. "Concrete is one of the most notorious carbon emitters in the construction industry." – Bullitt Center.org	Create conditions conducive to life, Be locally attuned and responsive, Evolve to survive	Certified as a Living Building by the International Living Building Institute
LEAF-LEVEL LIGHT CAPTURE + TRANSPIRATION	The building is "Net Positive" for solar as its over 500 solar panels generate more energy than the building uses annually	Leverage cyclic processes, Multifunctional design	"Net Positive" energy produced annually
TERMITE-MOUND / CHIMNEY-EFFECT NATURAL VENTILATION	The building has a living façade that adapts to the outside climate to ensure occupant comfort. This is done by using exterior louver shades, opening windows or heating or slightly cooling the radiant slab at each floor. Active systems are in place in case the façade is closed.	Use low-energy processes, Adapt to changing conditions	Naturally ventilated and opens, rotates, and closes different architectural elements to maintain occupant comfort.
CACTUS / NAMIB BEETLE WATER STRATEGY	"Net positive" for water by implementing rainwater harvesting and stormwater management. "Net positive" in this aspect means that the building creates more potable water than it uses.	Be resource efficient, Use readily available materials & energy	Building creates more potable water than it uses.
NACRE / BONE (MATERIAL HEALTH & EFFICIENCY)	Effort was made to ensure that products that did not contain "Red List" chemicals were used in the design and construction of the center.	Use life-friendly chemistry, Build from the bottom up	Did not use products with "Red List" chemicals

BIOMIMETIC STRATEGY / NATURAL MODEL	HOW THE BULLITT CENTER TRANSLATES IT	LIFE'S PRINCIPLE(S) EMBODIED	PERFORMANCE OUTCOME
FOREST FLOOR NUTRIENT CYCLING	100 % onsite composting toilets; Update: As of 2021, the onsite composting toilets have been replaced with a vacuum system that uses 70% less water!	Use cyclical processes, Break down into benign constituents	The vacuum pumps pull waste through a grinder… then into a collection tank. From the collection tank, waste goes into the public sanitary sewer system for treatment. Solids from the sewage treatment plant are converted into a human waste loop is then used as a fertilizer.
SALMON-RUN MIGRATION (DAYLIGHTING & VIEWS)	Daylight illuminates the interior "… for 90% of the time without the need for electric lighting… The lighting design incorporates simple lighting controls: manual dimming, occupancy sensors, photocells, and plain old wall switches…." – Bullitt Center	Be locally attuned (Pacific NW species), Create conditions conducive to life	The interior only needs electrical lighting 10% of the time during the day.

Quote from the Design Team:

"We didn't just want a green building. We wanted a building that functioned like the Pacific Northwest ecosystem that was here before Seattle existed – one that generates its own energy, captures and purifies its own water, operates efficiently with life-friendly materials, and ultimately gives back more to the environment than it takes."
– Denis Hayes (Bullitt Foundation President) & Jason F. McLennan (chief architect)

The Bullitt Center is one of the strongest biomimetic reference projects in the world because it proves the major Life's Principles can be achieved using today's technology and done so reasonably. The Bullitt Center remains the highest standard that every new Living Building (and every serious biomimetic project) is or should be measured against.

Find below more examples that show how biomimicry is being applied across the AEC industry in real-world projects and how emerging technologies are shaping future design possibilities.

1. SPIDER SILK (STRENGTH, FLEXIBILITY, ENERGY ABSORPTION)

Built Examples:

- **Beijing National Stadium (China)**
  - **Design Inspiration:** Spider silk's high tensile strength and flexibility.
  - **Key Features:** The stadium's intricate steel frame mimics spider silk's strength-to-weight ratio. The web-like structure provides flexibility and energy absorption, making it resilient to wind and seismic forces.
  - **Impact:** The "Bird's Nest" is a global architectural landmark demonstrating how biomimicry can inform structural efficiency.

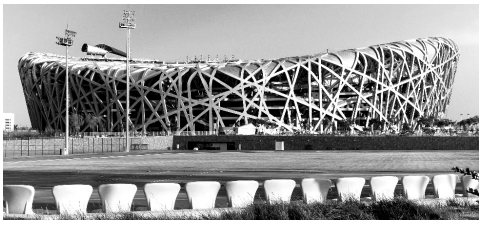


Figure 4.30. – The National Stadium (国家体育场), a.k.a. the Bird's Nest (鸟巢) in Beijing, China © CEphoto, Uwe Aranas Wikipedia

- **The Eden Project (UK)**
  - **Design Inspiration:** Spider silk's strength and tensile properties.
  - **Key Features:** The geodesic biomes' lightweight, flexible ETFE (ethylene tetrafluoroethylene) panels mimic the properties of spider silk, providing high strength with minimal material use. The panels are resilient to environmental stress, similar to spider silk's behavior under tension.
  - **Impact:** The project is an exemplary of how natural materials and biomimetic design principles can create efficient, low-carbon buildings.
- **The Millennium Bridge (UK)**
  - **Design Inspiration:** Spider silk's ability to handle tensile loads with minimal material.
  - **Key Features:** The suspension bridge utilizes high-strength steel cables that exhibit a spider silk-inspired structure, focusing on strength, minimal material use, and efficient load bearing.
  - **Impact:** The bridge's design maximizes tensile strength while minimizing environmental impact, proving the efficiency of spider silk principles in large-scale infrastructure.

2. HONEYCOMBS (GEOMETRIC EFFICIENCY, STRENGTH-TO-WEIGHT RATIO)

Built Examples:

- **Al Bahar Towers (Abu Dhabi, UAE)**
  - **Design Inspiration:** Diatom-like perforated structures and hexagonal grids.
  - **Key Features:** The façade incorporates hexagonal shading panels that adjust dynamically to the sun's position, inspired by the perforation patterns of diatoms. This system reduces solar gain and improves energy efficiency.
  - **Impact:** Al Bahar Towers demonstrate how nature-inspired designs can mitigate extreme climate conditions, reducing energy consumption in the harsh desert environment.



Figure 4.31. – Al Bahar Tower 1 in Abu Dhabi, United Arab Emirates © Aedas, Skyscrapercenter.com

- **The Crystal (London, UK)**
  - **Design Inspiration:** Honeycomb and nacre-inspired composite materials.
  - **Key Features:** The building's façade and cladding are made with tough, lightweight materials that use honeycomb-like structures to balance energy efficiency and strength.
  - **Impact:** The Crystal serves as a model for energy-efficient, sustainable building designs, combining biomimicry with cutting-edge materials science.

3. DIATOMS (POROSITY, LIGHTWEIGHT STRENGTH)

Built Examples:

- **Al Bahar Towers (UAE) (Refer to Figure 2.13 above)**
  - **Design Inspiration:** Diatom-like perforated structures.
  - **Key Features:** The façade of Al Bahar Towers is composed of dynamic hexagonal panels inspired by diatom structures. These panels adjust based on the sun's position, maximizing shading and reducing energy consumption.
  - **Impact:** The towers demonstrate how lightweight materials and responsive, diatom-inspired perforations can reduce energy costs while improving structural performance.

- **The Gherkin (London, UK)**
  - **Design Inspiration:** Diatom-like geometries for perforation and material distribution.
  - **Key Features:** The building's double-glazed façade features a series of ventilated spaces inspired by the natural perforated structure of diatoms, optimizing the distribution of light and heat.
  - **Impact:** The Gherkin shows how diatom-inspired facades can create highly efficient, energy-conserving buildings.

- **The Edge (Amsterdam, Netherlands)**
  - **Design Inspiration:** Lightweight, energy-efficient structural materials inspired by diatoms.
  - **Key Features:** The building's façade is designed with thin, perforated panels that provide shading and heat dissipation while minimizing material usage, similar to diatom microstructures.
  - **Impact:** The Edge demonstrates how diatom-inspired principles can be applied to office buildings, resulting in cutting-edge energy-efficient solutions.



Figure 4.32. – Exterior elevation of The Edge
© By AValečka – Own work, CC BY-SA 4.0, Commons Wikimedia

4. TERMITE MOUNDS (PASSIVE CLIMATE CONTROL, NATURAL VENTILATION)

Built Examples:

- **Eastgate Centre (Harare, Zimbabwe)**
  - **Design Inspiration:** Termite mound cooling and ventilation strategies.
  - **Key Features:** The Eastgate Centre uses a passive cooling system based on the principles of termite mound architecture. The building's design includes thick concrete walls, natural ventilation, and chimneys that draw in cool air and expel hot air.
  - **Impact:** This innovative use of natural climate control has reduced the building's energy consumption by over 90%, showcasing the potential of biomimicry in low-energy design.

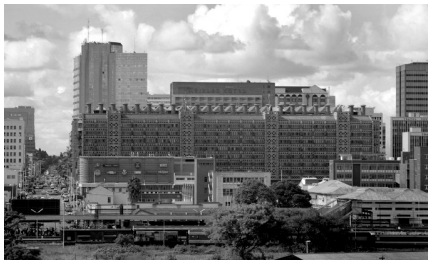


Figure 4.33. – The Eastgate Centre Shopping Centre & Office Building; The building is ventilated and cooled entirely by natural means.
© David Brazier – Wikipedia

- **The Louvre Abu Dhabi (UAE)**
  - **Design Inspiration:** Termite mound-inspired passive cooling techniques.
  - **Key Features:** The museum uses a large dome structure that mimics the natural thermal behavior of termite mounds. The dome's design ensures natural airflow and temperature regulation, reducing the reliance on artificial cooling systems.
  - **Impact:** The Louvre Abu Dhabi stands as an example of how biomimicry can be applied to large-scale, culturally significant buildings while achieving high energy efficiency.

- **The Green Building (USA)**
  - **Design Inspiration:** Termite mound-inspired natural ventilation systems.
  - **Key Features:** This office building in California uses passive cooling strategies derived from termite mounds, such as a ventilated double-skin façade, and a natural airflow system.
  - **Impact:** The building's energy consumption is significantly lower than that of typical office buildings, demonstrating how biomimetic design can optimize environmental performance.

5. TREES (BRANCHING, STRESS-BASED TAPERING, LOAD DISTRIBUTION)

Built Examples:

- **Sagrada Familia (Spain)**
  - **Design Inspiration:** Tree branching for structural optimization.
  - **Key Features:** Gaudí's design for the Sagrada Familia uses columns and arches that mimic tree-like structures, with tapered columns and branching supports designed to follow natural stress paths.

- **Impact:** The cathedral's iconic, nature-inspired design allows for efficient material use while achieving both beauty and stability.

- **Bosco Verticale (Milano, Italia)**
  - **Design Inspiration:** Trees for structural optimization and load distribution.
  - **Key Features:** The two residential towers in Milan are covered with thousands of trees and plants, which contribute to the building's natural cooling system and reduce energy consumption. The trees' branching patterns optimize wind resistance and structural integrity.
  - **Impact:** Bosco Verticale is a pioneering example of how tree-like design principles can enhance both sustainability and urban aesthetics.



Figure 4.34. – Bosco Verticale in Milano, Italia © Darsheni – Wikipedia

- **Chapel of St. Ignatius (USA)**
  - **Design Inspiration:** Tree branches and load distribution for architectural stability.
  - **Key Features:** The design of the chapel includes branching structural elements that mirror tree forms, with a central space supported by a network of slender, tapering columns.
  - **Impact:** The design maximizes space and creates a sense of openness, while the branching column structure efficiently distributes loads.

6. NACRE (MOTHER OF PEARL) – TOUGHNESS, LAYERED COMPOSITES, CRACK DEFLECTION

Built Examples:

- **City Hall in Newham formerly known as "The Crystal" (London, UK)**
  - **Design Inspiration:** Nacre's tough, layered structure.
  - **Key Features:** The building's façade and structural materials are designed using layered composites that mimic the tough, crack-resistant structure of nacre. This allows for high-performance, lightweight materials that can absorb impact and resist damage.
  - **Impact:** The use of nacre-inspired materials in the building reduces energy consumption while providing durability and resilience.



Figure 4.35. – Exterior View of City Hall, HQ for the GLA formerly known as "The Crystal" © By Matt Buck – Flickr – Wikipedia

- **Biomimetic Composite Materials (Various Locations, R&D)**
  - **Design Inspiration:** Nacre's alternating hard-soft layers for toughness.
  - **Key Features:** Researchers are exploring the use of composite materials inspired by nacre's structure, particularly in the aerospace and automotive industries. These composites combine lightweight materials with enhanced toughness, providing resistance to cracks and impacts.
  - **Impact:** These biomimetic composites could revolutionize material design for lightweight, high-performance applications.

- **Laminated Glass Panels (Global) – Nacre-Inspired Toughened Glass**
  - **Design Inspiration:** Nacre's layered structure for crack resistance.
  - **Key Features:** Some modern glass designs incorporate laminated glass with a soft core and harder outer layers, mimicking the structure of nacre. This improves the glass's ability to resist impacts and spread stresses across its surface.
  - **Impact:** This design makes glass more durable and safer in high-traffic or high-risk areas, such as façades and skylights.

7. FISH SCHOOLING (FLOW OPTIMIZATION, COLLECTIVE BEHAVIOR)

Built Examples:

- **The Al Bahar Towers (UAE)**
  - **Design Inspiration:** Collective, responsive behavior of fish schools.
  - **Key Features:** The façade of the Al Bahar Towers features dynamic, sun-responsive shading panels that open and close based on the movement of the sun, similar to the adaptive, collective behavior seen in fish schools.
  - **Impact:** The building's adaptive façade reduces energy consumption by blocking excess sunlight and heat while optimizing natural light flow into the building.
- **Burlington House (USA)**
  - **Design Inspiration:** Collective behavior and dynamic adaptation of fish schools.
  - **Key Features:** The building features an adaptive HVAC system that responds to real-time occupancy and environmental factors. This collective system, inspired by the schooling behavior of fish, optimizes energy use and indoor air quality.
  - **Impact:** By dynamically adjusting to changing conditions, the system reduces overall energy use and increases occupant comfort.
- **Olympic Village (East Village) (London, UK)**
  - **Design Inspiration:** Fish schooling's collective flow and energy efficiency.
  - **Key Features:** The village used a smart grid and natural ventilation systems inspired by fish schooling patterns, with systems that respond to collective usage patterns and external weather conditions.
  - **Impact:** This contributed to the village's energy-efficient design and its recognition for sustainability.



Figure 4.36. – East Village in Stratford; Originally an Olympic Village and now a Mixed-Use community © EG Focus – Wikipedia

8. BEEHIVES (GEOMETRIC EFFICIENCY, LOAD BEARING, HONEYCOMB STRUCTURES)

Built Examples:

- **The Gherkin** *(word for "pickled cucumber")* **(London, UK)**
  - **Design Inspiration:** Hexagonal geometry and structural efficiency of beehives.
  - **Key Features:** The building's façade incorporates a pattern of hexagonal glass and steel panels that optimize material use, much like the hexagonal efficiency of honeycombs. This design reduces the structural weight while maximizing stability and strength.
  - **Impact:** The Gherkin showcases how honeycomb-inspired geometric patterns can create energy-efficient, aesthetically pleasing buildings with optimal structural performance.



Figure 4.37. – The Gherki aka 30 St Mary Axe aka the Swiss Re Building © Wikipedia

- **Beijing National Aquatics Center (China)**
  - **Design Inspiration:** Honeycomb structure for optimized load distribution.
  - **Key Features:** The "Water Cube" uses a transparent honeycomb structure to create an aesthetically striking, energy-efficient building. The design maximizes the use of space and material while maintaining structural integrity.
  - **Impact:** The structure reduces energy consumption while providing an innovative and visually appealing solution for large-scale public buildings.
- **Maggie's Centre (UK)**
  - **Design Inspiration:** Beehive-like geometric efficiency for structure and stability.
  - **Key Features:** The building's design uses modular, geometric panels inspired by the efficiency of beehives to create a lightweight, stable structure. This allows for the creation of an open, inviting space for users while minimizing material use.
  - **Impact:** The project demonstrates how honeycomb and geometric principles can optimize space and material use in small to medium-sized structures.

PART 4 – INTEGRATED STRATEGY AND REGENERATIVE PERFORMANCE KNOWLEDGE CHECK (5 QUESTIONS)

1. How does the Al Bahar Towers in Abu Dhabi apply biomimicry principles?

A. By using a bioreactive façade to generate renewable energy

B. By incorporating dynamic mashrabiya screens that respond to the sun's position

C. By using termite mound-inspired passive cooling systems

D. By integrating a honeycomb structure for load distribution

2. What biomimicry principle is applied in the Bullitt Center's rainwater harvesting system?

A. Use life-friendly chemistry

B. Be resource efficient

C. Leverage cyclic processes

D. Build from the bottom up

3. Which building uses a bioreactive façade powered by algae to generate energy?

A. The Edge, Amsterdam

B. BIQ House, Hamburg

C. Bosco Verticale, Milan

D. Masdar City

4. How does the Eastgate Centre in Zimbabwe mimic termite mounds?

A. By using a honeycomb structure for load distribution

B. By using algae-powered bioreactors for energy generation

C. By incorporating passive cooling and ventilation systems

D. By integrating a dynamic façade that responds to sunlight

5. What is the primary biomimicry principle applied in the Bosco Verticale in Milan?

A. Build resilience through diversity

B. Use low-energy processes

C. Adapt to changing conditions

D. Use life-friendly chemistry

You made it to the finish line!
This concludes the final part, Part 4 of the course.
Continue to the Final Exam.

OUTLOOK AND CONCLUSION

As displayed in each part of this training on Biomimicry and Regenerative Design, it has been shown that mother nature has all the answers for the built environment. It is just a matter of the design professional implementing these tried and true, real-world solutions so much so that such design approaches become normalized.

In conclusion, use this information and the additional document (found at the QR code below) to start or continue your journey in biomimicry.

It has been a joy producing this training for you and us here at MRA Architecture & Design wish you a great day and everlasting success!

BIOMIMICRY AND REGENERATIVE DESIGN QUIZ ANSWERS | PARTS 1 – 4

PART 1 – Biomimicry and Regenerative Design Knowledge Check (5 Questions)

1. **What is the primary goal of Biophilic Design?**
   - *A. Improve the performance of buildings in relation to the environment; Incorrect.*
   - **B. Enhance occupant well-being and emotional connection to nature; Correct. Biophilic Design is a human-centric approach that focuses on improving the well-being of occupants.**
   - *C. Mimic nature's strategies for technical innovation; Incorrect.*
   - *D. Reduce energy consumption through passive cooling; Incorrect.*

2. **Which of the following best describes the goal of Biomimicry?**
   - *A. To create spaces that reduce stress and improve mental health; Incorrect.*
   - **B. To mimic nature's strategies to improve performance and sustainability; Correct. Biomimicry focuses on studying and emulating nature's systems, structures, and strategies to solve technical challenges in the built environment.**
   - *C. To enhance the aesthetic appeal of buildings through natural elements; Incorrect.*
   - *D. To increase biodiversity within urban environments; Incorrect.*

3. **Which of the following is an example of Biomimicry?**
   - *A. Adding indoor plants to an office space; Incorrect.*
   - **B. Designing a façade inspired by a pinecone's ability to open and close; Correct. Biomimicry involves using nature's strategies and systems to solve technical challenges.**
   - *C. Using natural wood for flooring; Incorrect.*
   - *D. Incorporating water features into a lobby; Incorrect.*

4. **What is the key difference between Biophilic Design and Biomimicry?**
   - *A. Biophilic Design focuses on technical innovation, while Biomimicry focuses on human well-being; Incorrect*
   - **B. Biophilic Design uses nature for experiences, while Biomimicry uses nature for solutions; Correct. The fundamental difference lies in their focus. Biophilic design is about creating experiences, while biomimicry is a technical approach.**
   - *C. Biophilic Design is used by engineers, while Biomimicry is used by architects; Incorrect*
   - *D. Biophilic Design is concerned with building performance, while Biomimicry is concerned with aesthetics; Incorrect*

5. **Which of the following is NOT one of the six overarching Biomimicry Life's Principles?**
   - *A. Be Resourceful with Material and Energy; Incorrect.*
   - *B. Use Life-friendly Chemistry; Incorrect.*
   - **C. Focus on Aesthetic Engagement; Correct. The six overarching Biomimicry Life's Principles are: Evolve to Survive, Adapt to Changing Conditions, Be Locally Attuned and Responsive, Use Life-friendly Chemistry, Be Resourceful with Material and Energy, and Integrate Development with Growth. While aesthetics may play a role in Biophilic Design, it is not a core principle of Biomimicry, which focuses on sustainability, efficiency, and resilience inspired by nature.**
   - *D. Adapt to Changing Conditions; Incorrect.*

PART 2 – Biomimicry in Structure and Thermal Systems Knowledge Check (5 Questions)

1. **What principle does trabecular bone demonstrate that is applied in structural optimization?**
   - **A. Stress-aligned lattices and void optimization; Correct. Trabecular bone distributes material only where needed.**
   - *B. High thermal mass and buoyancy-driven flow; Incorrect.*
   - *C. Hydrophilic and hydrophobic surface patterning; Incorrect.*
   - *D. Reflective surfaces and evaporative cooling; Incorrect.*

2. **Which natural model inspired the design of diagrid systems with angle-optimized diagonals?**
   - *A. Termite mounds; Incorrect.*
   - *B. Diatoms; Incorrect.*
   - **C. Bone and trabecular architecture; Correct. Bone's stress-based anisotropy supports the design of diagrid systems, where diagonal densities are optimized based on stress zones.**
   - *D. Nacre (Mother of Pearl); Incorrect.*

3. **What is a key feature of diatom-inspired façade panels?**
   - *A. High reflectivity to reduce solar heat gain; Incorrect.*
   - **B. Perforation fields optimized for bending and shear; Correct. Diatoms have porous silica exoskeletons with hexagonal micro-lattices and ribbed frameworks. These features inspire façade panels with perforation fields that optimize stiffness and reduce material use while maintaining structural integrity.**
   - *C. Hydrophobic coatings for water resistance; Incorrect.*
   - *D. Layered composites for crack arresting; Incorrect.*

4. **How does nacre (Mother of Pearl) achieve its exceptional toughness?**
   - *A. MX3D Bridge, Amsterdam; Incorrect.*
   - **B. Centre Pompidou-Metz, France; Correct. Nacre's structure consists of microscopic aragonite "bricks" and organic "mortar," creating a layered composite that resists cracking and absorbs stress.**
   - *C. Al Bahar Towers, UAE; Incorrect.*
   - *D. Striatus Bridge, Zaha Hadid Architects; Incorrect.*

5. **Which building example demonstrates tree-inspired branching load paths?**
   - *A. MX3D Bridge, Amsterdam; Incorrect.*
   - **B. Centre Pompidou-Metz, France; Correct. The roof of the Centre Pompidou-Metz is a branching hexagonal timber lattice inspired by tree canopies.**
   - *C. Al Bahar Towers, UAE; Incorrect.*
   - *D. Striatus Bridge, Zaha Hadid Architects; Incorrect.*

PART 3 – Biomimicry in Material Science and Water Management | Knowledge Check (5 Questions)

1. **What is the primary mechanism behind the self-cleaning property of the Lotus Leaf?**
   - *A. Hydrophilic surface that absorbs water; Incorrect.*
   - **B. Superhydrophobic surface with a unique micro/nano texture; Correct. The Lotus Leaf remains clean due to its superhydrophobic surface, which has a unique micro/nano texture and a dense layer of wax tubules.**
   - *C. Capillary action that traps water droplets; Incorrect.*
   - *D. Hygroscopic movement driven by humidity; Incorrect.*

2. **How does shark skin inspire anti-fouling finishes in architecture?**
   - *A. By using hydrophilic properties to attract water; Incorrect.*
   - **B. By mimicking riblets that reduce drag and prevent bacterial settlement; Correct. Shark skin is covered with dermal denticles that have riblets, which reduce drag and turbulence while preventing bacterial attachment. This principle is applied in anti-fouling finishes, such as Sharklet® surfaces, to deter microbial growth and improve hygiene.**
   - *C. By creating a porous structure for water absorption; Incorrect.*
   - *D. By using capillary action to filter water; Incorrect.*

3. **What principle of pinecones is applied in responsive cladding systems?**
   - *A. Superhydrophobic surface for water repellency; Incorrect.*
   - **B. Hygroscopic movement driven by moisture changes; Correct. Pinecones exhibit hygroscopic properties, where their scales open and close in response to humidity. This principle is applied in responsive cladding systems that adapt to environmental moisture levels, optimizing ventilation and moisture control.**
   - *C. Riblets for drag reduction; Incorrect.*
   - *D. Turgor-driven response to environmental stimuli; Incorrect.*

4. **How do mangrove roots inspire water filtration systems in architecture?**
   - *A. By using ribbed frameworks for structural strength; Incorrect.*
   - **B. By filtering saltwater through specialized root structures; Correct. Mangrove roots filter saltwater and conserve freshwater through their specialized structures.**
   - *C. By creating superhydrophobic surfaces for water repellency; Incorrect.*
   - *D. By using capillary action to absorb and retain water; Incorrect.*

5. **What is the key feature of spider silk that inspires water-resistant building materials?**
   - *A. Hydrophilic surface for water absorption; Incorrect.*
   - **B. Nano-scale surface hydrophobicity and tensile strength; Correct. Spider silk is both water-repellent and extremely strong due to its nano-scale surface hydrophobicity and tensile properties.**
   - *C. Hygroscopic movement for moisture retention; Incorrect.*
   - *D. Capillary action for water dispersion; Incorrect.*

PART 4 – Integrated Strategy and Regenerative Performance | Knowledge Check (5 Questions)

1. **How does the Al Bahar Towers in Abu Dhabi apply biomimicry principles?**
   - *A. By using a bioreactive façade to generate renewable energy; Incorrect.*
   - **B. By incorporating dynamic mashrabiya screens that respond to the sun's position; Correct. The Al Bahar Towers feature 2,098 computer-controlled mashrabiya screens that open and close in response to the sun's position.**
   - *C. By using termite mound-inspired passive cooling systems; Incorrect.*
   - *D. By integrating a honeycomb structure for load distribution; Incorrect.*

2. **What biomimicry principle is applied in the Bullitt Center's rainwater harvesting system?**
   - *A. Use life-friendly chemistry; Incorrect.*
   - *B. Be resource efficient; Incorrect.*
   - **C. Leverage cyclic processes; Correct. The Bullitt Center's rainwater harvesting system creates a closed-loop process where rainwater is collected, filtered, and reused. This aligns with the biomimicry principle of leveraging cyclic processes, mimicking nature's ability to recycle resources efficiently.**
   - *D. Build from the bottom up; Incorrect*

3. **Which building uses a bioreactive façade powered by algae to generate energy?**
   - *A. The Edge, Amsterdam; Incorrect.*
   - **B. BIQ House, Hamburg; Correct. The BIQ House in Hamburg features a bioreactive façade with 129 algae-filled bioreactors. These panels generate biomass and heat, provide shading, and act as thermal insulation, showcasing the biomimicry principle of "Use multifunctional design."**
   - *C. Bosco Verticale, Milan; Incorrect.*
   - *D. Masdar City; Incorrect.*

4. **How does the Eastgate Centre in Zimbabwe mimic termite mounds?**
   - *A. By using a honeycomb structure for load distribution; Incorrect.*
   - *B. By using algae-powered bioreactors for energy generation; Incorrect.*
   - **C. By incorporating passive cooling and ventilation systems; Correct. The Eastgate Centre mimics termite mounds by using passive cooling and ventilation systems. Thick walls, natural ventilation, and chimneys regulate the building's temperature, reducing energy consumption by over 90%.**
   - *D. By integrating a dynamic façade that responds to sunlight; Incorrect.*

5. **What is the primary biomimicry principle applied in the Bosco Verticale in Milan?**
   - **A. Build resilience through diversity; Correct. Bosco Verticale incorporates 900 trees and thousands of shrubs and plants, creating a biodiverse environment that supports local wildlife, reduces energy consumption, and improves air quality. This aligns with the biomimicry principle of "Building resilience through diversity."**
   - *B. Use low-energy processes; Incorrect.*
   - *C. Adapt to changing conditions; Incorrect.*
   - *D. Use life-friendly chemistry; Incorrect.*

Notes

Notes

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INTEGRATING GENERATIVE AI INTO THE ARCHITECTURAL WORKFLOW

Course # AIAPDH276
4 LU | HSW Hours

FINAL EXAM (25 QUESTIONS)

1. **Generative AI is designed to do what?**
   A. Redesign existing photos from social media only
   B. Produce new, original outputs that mimic the data it has been trained on
   C. Send text messages to random phone numbers
   D. Make sandwiches

2. **Who doesn't train the data for Generative AI?**
   A. Researchers & Engineers
   B. Human Labelers / Annotators
   C. Takers
   D. Domain Experts

3. **Large Language Models (LLMs) are designed to do what?**
   A. To understand, generate, and manipulate human language
   B. To reword existing text
   C. To never manipulate human language
   D. To teach English and spread the language

4. **_____% of companies leverage AI for managing customer relationships.**
   A. 25%
   B. 0%
   C. 46%
   D. 100%

5. **When entering text into a Generative AI it is important to use what?**
   A. Numbers only
   B. Natural language
   C. Symbols only
   D. Unnatural language

6. **Which prompt will yield a more detailed image using a Text-to-Image Generative AI?**
   A. "Design a modern office headquarters."
   B. "Design a modern office headquarters inside a strip mall with separate zones for a CEO office, sales offices, a unisex restroom, a break room, storage, a modern butt-glazed conference room, and a showroom. The overall aesthetic should be minimalist, using natural materials like wood and stone, complemented by sleek glass partitions and open spaces. Include biophilic design elements with plenty of natural light."
   C. "Show me an office."
   D. "Design a strip mall inside an modern office headquarters."

7. **What is the definition of Latent-Space Modeling?**
   A. It allows you to explore design variations by not sampling from a trained model's latent space.
   B. It does not allow you to explore design variations by sampling from a trained model's latent space.
   C. It allows you to explore design variations by sampling from a trained model's latent space.
   D. It allows you to explore variations by sampling from a untrained model in outer space.

8. **Which generative AI is great for generating detailed design briefs?**
   A. Image-To-Image
   B. Text-To-Image
   C. Latent-Space Modeling
   D. Large Language Models (LLMs)

9. **What is a shot-based prompt?**
   A. A prompt that has an example for the AI to follow
   B. A prompt with a basketball reference
   C. A prompt that you only get one shot for it to work
   D. A prompt that is assigned a persona

10. **With prompt chaining, you take a _____ task and break it up into _____ tasks to reach your answer.**
    A. Simpler, complex
    B. complex, simpler
    C. complex, complex
    D. simple, simple

11. **Regarding _____ automation, can AI automate tracking changes between specification versions?**
    A. elevation drawings
    B. drawings
    C. specification writing
    D. sketch

12. **Regarding Code & Zoning summaries, what can AI automate?**
    A. Drawing a grease trap detail specific to a certain jurisdiction
    B. Summaries of applicable IBC sections
    C. On-Site Dead, Dying, Hazardous report for a specific parcel
    D. Write a perfect general notes section without human oversight

13. **Regarding cost-estimating first passes, what can AI automate?**
    A. Three-Point Estimates
    B. Rough-order-of-magnitude (ROM) cost estimates
    C. Parametric Estimates
    D. Bottom-Up Estimates

14. **Regarding RFI and Submittal automation, what can AI automate?**
    A. Sketch quick, detailed solutions
    B. Draw enlarged details for RFIs
    C. Suggest standard approval or denial language
    D. Provide detailed written responses reference sheets with no human oversight

15. **What steps should be followed for integration of an AI strategy for an architecture firm (in order from start to finish)?**
    A. 1) Standardize inputs, 2) Centralize Prompts, 3) Human-in-the-loop QA
    B. Draft schedules & work plans
    C. 1) Human-in-the-loop QA, 2) Standardize inputs, 3) Centralize Prompts
    D. 1) Centralize Prompts, 2) Standardize inputs, 3) Human-in-the-loop QA

16. **What is the stance of NCARB on AI and its use?**
    A. Keeping homes facing public streets in good condition only
    B. AI is a tool – it is not a replacement for professional judgement
    C. Keeping semi-private spaces in communities in good condition only
    D. AI is a tool – it is a replacement for professional judgement

17. **What is the stance of ASME on AI and its use?**
    A. ASME does not require authors to fully report their use of AI tools
    B. AI tools are considered acceptable authors
    C. AI tools are not considered acceptable authors
    D. ASME does not have a stance on AI yet

18. **Regarding Professional Liability Insurance (PLI) and AI a firm should have _____?**
    A. a clear and well-thought out usage policy
    B. nothing in place
    C. AI administer policy with no human oversight
    D. a clear usage policy for non-related AI matters

19. **What was the punishment given to the solicitor in Australia who used an AI generated false citation?**
    A. None
    B. No longer entitled to practise (sic) as a principal lawyer
    C. Expelled from Australia
    D. Given the death penalty

20. **What is considered the landmark case regarding AI hallucinations?**
    A. Chiefs v. Bills
    B. IBC v. ICC, Inc.
    C. Castel v. GenAI
    D. Mata v. Avianca, Inc.

21. **What is a core principle regarding the AEC industry and AI-generated content? The design professional is _____.**
    A. Not responsible at all since they did not create the Generative AI
    B. Fully responsible for the final output or work product, regardless of the amount of AI assistance
    C. Fifty percent responsible for the final input and output
    D. Partially responsible for the final output or work product

22. **Regarding professional oversight, AI is a tool and in no way a substitute for _____ and _____.**
    A. Justice and Liberty for all
    B. Generative AI and Traditional AI
    C. Licensed oversight and Professional judgement
    D. Hand drafting and Building Information Modeling

23. **What is Human-in-the-Loop AI?**
    A. A closed-loop system where human judgement is embedded at key points in the AI lifecycle
    B. A open loop system where AI judgement monitors key points in the AI lifecycle
    C. A blended loop system where human judgement is not included in the AI lifecycle at all
    D. A geothermal open loop system for residences

24. **What are the 4 key points in the AI lifecyle where human judgement is embedded?**
    A. Training, Validation, Deployment, and Engineering
    B. Training, Validation, Deployment, and Architecture.
    C. Training, Non-Validation, Deployment, and Architecture
    D. There are none as human judgement is not needed

25. **What does "deployment" mean in relation to the Human-in-the-Loop and it being a key embedment point?**
    A. Arrival at a military drop point
    B. AI monitors live predictions and overrides when necessary
    C. Humans monitor live predictions, override when necessary, and feed corrections back into the loop.
    D. No action is to be taken by any humans at any point and time

END OF FINAL EXAM

INTEGRATING GENERATIVE AI INTO THE ARCHITECTURAL WORKFLOW

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Course Summary

This 4-hour LU/HSW course introduces AEC professionals to Generative AI fundamentals, effective prompting techniques, practical AEC applications, and key ethical, legal, and professional responsibility considerations.

Learning Objectives

1. **Learn** how Generative AI differs from Traditional AI and **Understand** how Generative AI works.
2. **Understand** the different prompting strategies and the main types of Generative AI.
3. **Identify** Generative AI tools and their use for AEC related tasks.
4. **Analyze** the legal landscape regarding use of AI-generated content.

Course Structure

- ✓ **PART 1 –** Generative AI vs. Traditional AI and Generative AI Fundamentals
- ✓ **PART 2 –** Generative AI Prompting Strategies, Types, and Exercises
- ✓ **PART 3 –** Generative AI for AEC: AI for Automation and Business Efficiency
- ✓ **PART 4 –** Ethics, Intellectual Property (IP), and the Future

PART 1 – GENERATIVE AI vs. TRADITIONAL AI AND GENERATIVE AI FUNDAMENTALS

Learning Objective No. 1:
Learn how Generative AI differs from Traditional AI and Understand how Generative AI works.



Ai has taken the world by storm and while everyone is getting drenched, some are running for shelter, some are opening umbrellas while others learn to dance in the rain. Ai isn't going anywhere – and as the quote goes "If you can't beat 'em, join 'em".

So, consider this training an introduction to Generative AI with an additional view through the lens of the AEC industry and how you can make it an ally and an asset and not a subject for verbal punishment in the break room.

GENERAL: TRADITIONAL AI VS. GENERATIVE AI

First, let's look at how Traditional AI differs from Generative AI.

TRADITIONAL AI	GENERATIVE AI
Follows rules	**Creates new content**
Uses structured data	**Needs large datasets**
Solves specific problems	**Focus on creativity**
Rigid and predefined	**Flexible and Diverse**
Simpler models	**High computational needs**
Automates tasks	**Enhances creativity**
Risks biased decisions	**Risk of misleading content**
Advances problem-solving	**Revolutionizes content creation**

Traditional AI versus Generative AI through an AEC lens. See below:

DIFFERENCES BETWEEN TRADITIONAL AI AND GENERATIVE AI	
TRADITIONAL AI	GENERATIVE AI
PURPOSE	PURPOSE
Traditional AI: *Classifies, predicts, or decides.* Example: "Is this email spam or not?"	**Generative AI:** *Creates.* Example: "Write an email in a friendly tone."
OUTPUT TYPE	OUTPUT TYPE
Traditional AI: Numeric labels, categories, yes/no answers.	**Generative AI:** Text, images, code, videos, sounds, new content that didn't exist before.
DATA USAGE	DATA USAGE
Traditional AI: Learns to recognize patterns.	**Generative AI:** Learns to replicate and recombine patterns creatively.
ANALOGIES	ANALOGIES
Blueprint Reader vs. Blueprint Creator **Traditional AI** is like an *engineer* who looks at a blueprint and says, "This is a kitchen" or "This is a load-bearing wall."	**Blueprint Reader vs. Blueprint Creator** **Generative AI** is like an *architect* who designs a brand-new blueprint based on requirements.
Building Inspector vs. Building Designer **Traditional AI** is the inspector who checks a building and reports, "This tenant spaces complies with code."	**Building Inspector vs. Building Designer** **Generative AI** is the designer who imagines and sketches a whole new building concept.

DIFFERENCES BETWEEN TRADITIONAL AI AND GENERATIVE AI	
TRADITIONAL AI	GENERATIVE AI
ANALOGIES *(continued)*	ANALOGIES *(continued)*
Furniture Cataloger vs. Interior Stylist **Traditional AI** labels objects: "This is a chair... this is a sofa."	**Furniture Cataloger vs. Interior Stylist** **Generative AI** creates a unique room layout or style never seen before.
Material Classifier vs. Material Inventor **Traditional AI** identifies materials: "This is concrete; this is steel."	**Material Classifier vs. Material Inventor** **Generative AI** invents new material combinations or proposes new material types.
City Map Reader vs. City Planner **Traditional AI** reads and classifies parts of a city map.	**City Map Reader vs. City Planner** **Generative AI** imagines and drafts a new urban district with streets, parks, and buildings.
Engineer **Traditional AI** is like a structural engineer checking if a beam can carry a load.	**Engineer** **Generative AI** is like software that proposes an entirely new beam shape or truss design optimized for strength and cost.
General Contractor **Traditional AI** is like a contractor identifying what tasks need to be done on-site.	**General Contractor** **Generative AI** is like a tool that automatically creates a full construction schedule and workflow plan from scratch.

GENERATIVE AI

What is Generative AI?

Generative AI is a type of artificial intelligence that can create new content – such as text, images, music, or even videos – all based on patterns learned from existing data.

Unlike traditional AI systems that perform tasks like classification, generative AI is designed to produce new, original outputs that mimic the data it has been trained on.

> ***"Generative artificial intelligence (AI) tools use machine learning models trained on massive pools of information to learn patterns from data to create novel content like text, images, audio, or video in response to a prompt. Unlike internet searches, generative AI tools do not use algorithms to locate and curate existing sources. Instead, they create new content by predicting what word, sound, or pixel would come next in a pattern."***
>
> ***– Teaching.Pitt.edu***

DATA TRAINING

Who "trains" the data for Generative AI?

Several groups are involved such as researchers & engineers for AI companies, Human Labelers / Annotators, Domain Experts for specialized models, and Users such as professionals in the AEC industry.

> ***"…AI trainers teach AI assistants to understand human language. They do this by feeding examples of real utterances to help the AI assistant better understand the meaning of peoples (sic) speech, or written language.***
>
> ***AI trainers analyze common topics discussed by users and how they ask for certain information while talking to your chatbot or voice assistant. These insights are used to continuously improve the cognition of your AI assistant and require a structured AI training workflow consisting of testing, updating, and measuring again…"***
>
> ***– Conversation Design Institute***

Find the tasks for each user group shown in more detail below, you have probably come across these roles on job boards, et. cetera – there is a high demand.

Researchers & Engineers

- collect large datasets
- clean and organize them
- design the model architecture
- run the training on large clusters of computers

Human Labelers / Annotators

- rating responses
- labeling examples
- correcting model mistakes
- providing feedback on quality and safety

Domain Experts

For medical, legal, financial, building code or scientific models, subject-matter experts (SMEs) help validate and curate datasets. We have even participated in this before, it was very interesting and very time-consuming.

Users

When a company allows it, user feedback or opt-in data helps improve future training – but only if the user explicitly consents.

> ***"AI is helping disaster response teams predict and respond to natural disasters. Tools like IBM's Watson Decision Platform for Agriculture are used to predict the impact of hurricanes and floods, aiding governments and NGOs in preemptive action."***
>
> ***– Vellum AI***

HOW IS THE TRAINING DONE?

Step 1: Data Collection

AI companies gather large amounts of publicly available or licensed text, images, audio, etc. including but not limited to books, articles, websites, code repositories, and other datasets.

Step 2: Scrub (Clean and filter)

Engineers use tools and rules and sometimes human reviewers to remove:

- duplicate content
- personal data
- harmful or low-quality information
- spam, broken text, etc.

A digital colander if you will.

Step 3: Train the model

Massive GPU/TPU clusters run algorithms that teach the model to predict the next word, pixel, or token. This is the "heavy lifting" part:

- trillions of examples
- huge compute power
- days or weeks of continuous training

Step 4: Fine-tuning

After the base model is trained, human experts refine it by:

- giving it example conversations
- correcting mistakes
- rating answers
- guiding tone, style, and safety

This step teaches the model to follow instructions and behave usefully.

Step 5: Continuous improvement

After release, the model may be improved using:

- new data
- safety testing
- evaluation from human reviewers
- user feedback (only when users opt in)

Again, Generative AI models learn patterns and structures from large datasets. After training, they can generate new outputs that resemble the examples they learned from.

For example:

- A text model can write essays, answer questions, or create stories.
- An image model can generate pictures from a description. *(helpful for when a prospective client is trying to share their vision with you)*
- A music model can compose melodies in a certain style.

"46% of companies leverage AI for managing customer relationships." – Vellum AI



INTERACTING WITH GENERATIVE AI TO SPEAK TO AI YOU NEED TO SPEAK "PROMPT".

What is a prompt? Simply put, it is what you type (your input) into the textbox of whatever AI you are using to obtain specific results.

Think of your input as "ice breakers" or conversation starters. Basically "junk in and junk out" i.e. your results or AI output are only as good as your input or text you type in the textbox. Thus, learning how to write a quality prompt is essential.

AI PROMPT EXAMPLES	
☹ BAD PROMPT EXAMPLE	GOOD PROMPT EXAMPLE
"Make a website look fantastic."	"Design an intuitive and responsive navigation menu for a mobile travel app."

WRITING A PROMPT

Before we get into the different types of prompts/prompting that you use to speak to AI, here is some information you can use to assist you in writing an effective prompt that yields the results you desire. Here are questions that should be answered and addressed when creating your first prompt. See the table above and the text below:

- **What result do you want?** ("Write an email…")
- **Who is your audience?** ("…to my client…")
- **Specify the tone of your input.** ("…with a professional yet friendly tone as I have known them and worked with them for 2 years…")
- **What keywords or phrases are important?** ("…the topic of the email is to ~~see~~ find out if they need my services or if there is anything my firm can help them with…)
- **How do you want the output presented?** ("…the email must be less than 23 words or more…")
- **Provide examples if able so you can teach the AI** ("…here is an example copied and pasted below from an email I received and liked…")
- **Refine, refine, and refine until the desired output is receiveD.**

The final prompt that we input into ChatGPT:

Write an email to my client with a professional yet friendly tone as I have known them and worked with them for 2 years the topic of the email is to find out if they need my services or if there is anything my firm can help them with the email must be less than 23 words or more here is an example copied and pasted below from an email I received and liked

"Hi [Client Name], hope you're well! I was thinking about our work on [Project], and wanted to see if you have any upcoming needs where [Your Service] could help. Let me know if you'd like to chat!"

AI Output:

Here's a draft for your email:

Subject: Checking In

Hi [Client Name], hope you're doing well! I wanted to touch base and see if there are any upcoming projects where [Your Service] could support you. Let me know if you'd like to catch up!

Best regards,

[Your Name]

This keeps it friendly, professional, and leaves the door open for future collaboration.

"…Using natural language is one of the most critical parts of effective AI prompting. Think of it like having a conversation with AI. You should write your prompts in a way that mimics everyday speech. That way, AI tools can better understand what you're asking for. The words you use and the way you phrase things can significantly impact the output you receive…"
– "Tips for Effective Prompting" Atlassian

YOUR TURN TO WRITE A PROMPT

So, as you can see below, we did not quite get a top score for our email prompt but hey we received a "Good" along with a breakdown on how the prompt can improve. So now it is YOUR turn, so let's see how you fare.

Click on any of the links below and visit any of the following prompt evaluation websites. You will receive free feedback and even a score (like the one below) on the quality and effectiveness of your prompt along with a detailed breakdown.

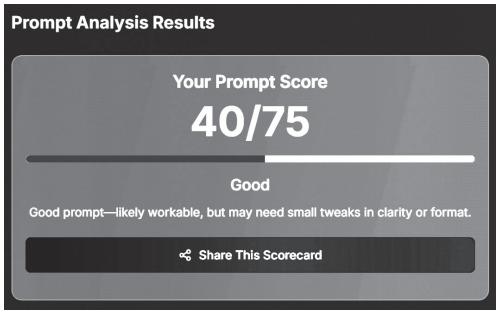


Figure 1.1 The score for the email prompt above, what was your prompt score? © agenticworkers.com, Prompt Engineering Scorecard

PROMPT EVALUATION WEBSITES

ChatGPT Prompt Evaluator 5.2

by Mickael Lherminez

Prompt Engineering Scorecard (100 characters minimum)

by Agentic Workers Tool

How did you do? We are guessing 75 out of 75!
You made it to the finish line!
This concludes Part 1 of the course.
Next up is your Part 1 Quiz!

PART 1 – GENERATIVE AI VS. TRADITIONAL AI AND GENERATIVE AI FUNDAMENTALS

KNOWLEDGE CHECK (5 QUESTIONS)

1. **What is the primary difference between Traditional AI and Generative AI?**
   - A. Traditional AI creates new content, while Generative AI classifies data
   - B. Traditional AI focuses on creativity, while Generative AI automates tasks
   - C. Traditional AI solves specific problems, while Generative AI creates new content
   - D. Traditional AI uses large datasets, while Generative AI uses structured data

2. **Which of the following is an example of Generative AI in the AEC industry?**
   - A. Identifying whether a material is concrete or steel
   - B. Designing a new urban district with streets, parks, and buildings
   - C. Checking if a building complies with local code
   - D. Predicting the energy consumption of a building

3. **What is the role of Human Labelers in training Generative AI models?**
   - A. Designing the model architecture
   - B. Providing feedback on quality and safety
   - C. Collecting and organizing large datasets
   - D. Running training on large clusters of computers

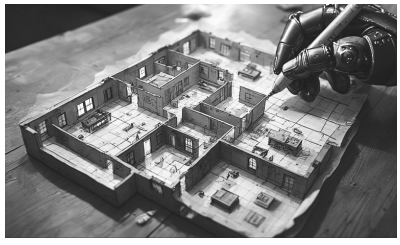
4. **What is the purpose of the "fine-tuning" step in Generative AI training?**
   - A. To collect and clean large datasets
   - B. To teach the model to predict the next word or pixel
   - C. To refine the model's behavior, tone, and safety
   - D. To evaluate the model using user feedback

5. **Which of the following is an example of a well-written AI prompt?**
   - A. "Make a website look fantastic."
   - B. "Design an intuitive and responsive navigation menu for a mobile travel app."
   - C. "Write something creative about architecture."
   - D. "Create a design that is good."

This concludes Part 1 of the course.
Let's continue to Part 2!

PART 2 – GENERATIVE AI PROMPTING STRATEGIES, TYPES, AND EXERCISES

Learning Objective No. 2:
Understand the different prompting strategies and the main types of Generative AI.



There are many different approaches one can take when looking to extract a response from Generative AI. In our research, we have found up to 10 different prompting types so let's look at all of them as they should all be in your tool kit when engaging AI and using prompting. They are as follows:

1. Zero-Shot (Shot = Example, thus no examples)

1.1. The prompt is clear, concise, and direct. Example below:

1.1.1. Prompt: Convert this to the future tense: I went to the store.

Output: The future tense version would be: "I will go to the store."

2. One-Shot or Few-Shot or Shot-Based (Shot = Example)

2.1. Along with the prompt, provide example(s) for the AI to follow when it delivers the output. An example of a few-shot prompt is below:

2.1.1. Prompt:

Classify the food below as typically served hot or cold.
Food: I have a milkshake. Typically served: Cold
Food: I have pizza. Typically served: Hot
Food: I have chargrilled oysters. Typically served:
Output: Typically served: Hot



Figure 2.0 Fresh and hot pizza! © Jonathan Hidalgo, pexels.com

3. System

3.1. This prompt technique defines the AI's role it is to play, task, style, and constraints. Example below:

3.1.1. Prompt: You are a friendly travel agent (role). Recommend a sunny vacation spot for adventure travelers, focusing on activities (task). Keep descriptions under 150 words (constraints) and use a numbered list. (style)

4. Role

4.1. Assign a persona to AI, context, and a point of view.

4.1.1. Prompt: Act like Patrick Mahomes. I am a superfan and asking him how many superbowls he has won with the Chiefs.

Output:
Yo, what's up, man! I appreciate the love. Seriously, the support from the Kingdom is what keeps us going every single Sunday.

To answer your question, as of right now, we've been blessed to bring three Super Bowl championships back to Kansas City!

It's been an incredible journey so far:

- Super Bowl LIV against the Niners.
- Super Bowl LVII against the Eagles.
- Super Bowl LVIII back-to-back against the Niners again.

But you know me – I'm never satisfied. The job isn't finished. We're always chasing that next one because we want to keep making history for the best fans in the world.

See you at GEHA Field at Arrowhead! Let's go!

Would you like me to break down my favorite play from one of those championship runs?

5. Contextual

5.1. Add context or specific background information to the prompt, create the state of mind that AI has and is answering from. Example below:

5.1.1. Prompt: You are an architect alive in 1894 practicing architecture in London. You are from a well-off family. Share the style of architecture you design in and name 3 of your clients. Be brief. Give their name, title, and one sentence regarding what they do.

Output:

I find myself most devoted to the Queen Anne Revival style, blending the warmth of red brick with the elegance of terracotta ornamentation and Dutch gables to create a look that is both stately and charmingly asymmetrical.

Here are three patrons who have recently engaged my services:

- Lord Arthur Penthaligon, Earl of Pembroke

  A distinguished member of the House of Lords who manages vast ancestral estates and seeks a modern hunting lodge in the Scottish Highlands.
- Dr. Silas Whitby, Chief Surgeon at the Royal London Hospital

  A pioneer in antiseptic surgical techniques who has commissioned a private laboratory and residence in Bloomsbury.
- Miss Helena Sterling, Director of the Sterling School for Girls

  An advocate for women's higher education who requires a new dormitory designed with ample light and proper ventilation.

  Would you like me to describe the specific ornamental details I am planning for Miss Sterling's facade?

6. Step-Back

6.1. A technique where you ask AI to identify and solve a broad, fundamental concept before asking a specific, complex question. This approach is ideal for complex, open-ended, creative writing, theme exploration, breaking down tasks requiring a lot of logic, or abstract problems. This is multi-step process, example below:

6.1.1. The Hard Question: "Will a car fit inside a standard 20-foot shipping container?"

The "Step-Back" Prompt:

Step Back Prompt: "What are the standard dimensions of a car and a 20-foot shipping container?"

Output: "A car is approx. 14ft long; a container is 20ft long."

The Original Question Prompt: "Based on those dimensions, will the car fit inside?"

AI Output: "Yes, with 6 feet of clearance."

7. Chain of Thought (CoT)

7.1. This approach improves AI reasoning by asking questions that force the AI to break problems into steps before reaching a final output. This is typically used with mathematics, computer coding, or complex decision making. Example below:

Prompt: When I was 5 years old, my partner was 4 times my age. Now I am 20. How old is my partner?

Output:

To find out your partner's current age, we can follow these steps:

1. Determine the partner's age in the past: When you were 5 years old, your partner was 4 times your age: 5 x 4 = 20 years old
2. Calculate the age difference: The difference in your ages is constant: 20 – 5 = 15 years old Your partner is 15 years older than you.
3. Determine the partner's current age: Now that you are 20, we add the 15-year difference to your current age: 20 + 15 = 35
4. Your partner is 35 years old.

8. Self-Consistency

8.1. We call this the "Best out of 3" prompt as you are asking the AI the same question multiple times (or "running the prompt" multiple times) and selecting the answer that is returned by the AI the most.

Refer to the image below for an example.

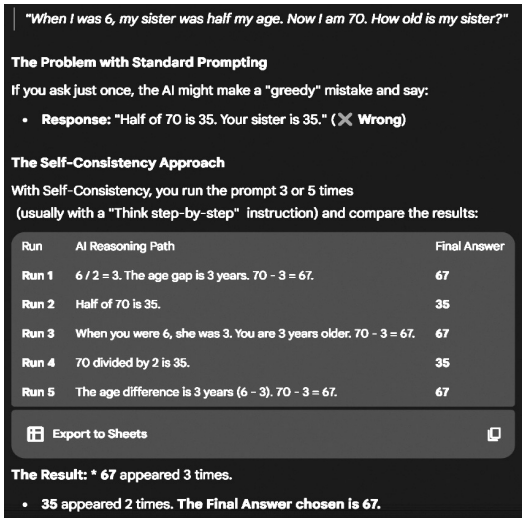


Figure 2.1. Example of Self-Consistency Prompt. © gemini.google.com

9. Tree of Thought (ToT)

9.1. This is a prompt type that is more creative and provides more well-reasoned outputs because it can explore multiple well-reasoned paths at once which allows it to perform as an expert problem solver.

Refer to the illustration below:

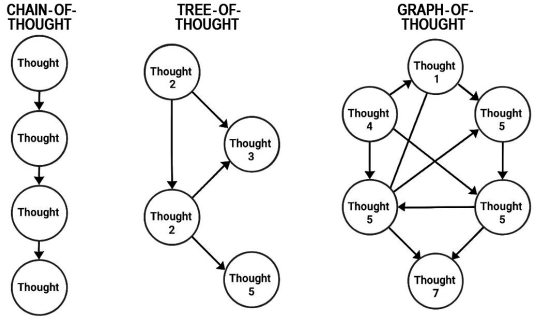


Figure 2.2. Example of Tree of Thoughts (ToT) Prompt. © Abduldattijo of pub.towardsai.net

10. ReAct (Reason + Act)

10.1. This prompt allows AI to solve real-world problems in real time. How? By following a thought-action-observation loop. This high-level prompt requires an understanding of programming as the AI would need to make API calls, search the internet, or running code. It basically mimics the way we humans approach a problem.

Prompt Chaining

Finally, we have Prompt Chaining, which is somewhat self-explanatory. You basically take a complex task or prompt and break it up into little simpler tasks or prompts to reach the answer to your initial complex task or prompt. See below:

"Here our complex prompt is: "Consider the given text in Spanish. Translate it into English. Find all the statistics and facts used in this text and list them as bullet points. Translate them again into Spanish."

To convert this complex prompt into simple prompts, we can break down the main goal into smaller actions or tasks, and we can create a chain of prompts as below:

1. "Read the given Spanish text."
2. "Translate the text into English language."
3. "Fetch the statistics and facts from the text."
4. "Create a bullet point list of all these facts."
5. "Translate them in Spanish language." – IBM

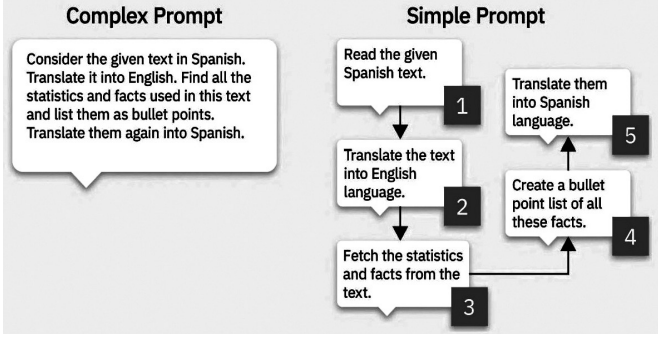


Figure 2.3 Prompt Chaining Example © IBM.com

We found this great resource that covers the prompting techniques we mentioned also: **PromptingGuide.ai**



THE THREE TYPICAL GENERATIVE AI TYPES

Now that you are familiar with prompts and the different prompt techniques available to you – let's look at the 3 Generative AI types. They are all involved in creating *new content* based on learned patterns in data as stated earlier. See below:

1. Text-to-Image AI
2. Latent-Space Modeling
3. Large Language Models (LLMs)

TEXT-TO-IMAGE AI

Text-to-image refers to the process of generating images based on textual descriptions using artificial intelligence models. These models take input in the form of a text prompt (e.g., "A futuristic cityscape at sunset") and generate an image that matches or reflects the content of the description.

It is built using deep learning techniques, specifically architectures like generative adversarial networks (GANs) or diffusion models. The model is trained on large datasets of images paired with descriptive text to learn the relationships between words and visual elements. Once trained, the model can generate new images based on any given text prompt.

Attributes

- **Generates new content**: These models produce new images from scratch.
- **Edits existing content**: These models allow you to edit existing images based on your text prompt.
- **Unsupervised learning**: They often learn patterns in data (e.g., text-image pairs) without explicit human labeling.
- **Creative generation**: The ability to generate unique outputs (images) that didn't exist before.

AI Models: Models like Stable Diffusion, DALL·E 2, Google Gemini (also an LLM), and MidJourney.



Figure 2.4 Black Cat with Sunglasses © Perchance.org

EXERCISES

Exercise 1: If you input the text "A black cat wearing sunglasses sitting on a beach," the model will generate an image that visualizes this scene page right. We used Perchance ai text to image generator to create this image and we applied an "Art Style" of "1990s Photo". *(See Figure 2.4 above)*

Exercise 2 for you: Click the hyper link and go to PerChance.org and type in the prompt below:

"Architect dressed in a snow suit standing on the top of a high-rise building"

Exercise 3: We went more in-depth and explored images you would typically find produced in the office of an AEC professional. We believe that the Text-to-Image Generative AI is great for quickly visualizing design concepts, spatial relationships, and interior or exterior renderings of architectural projects. *PerChance was used to produce the images below, unless noted otherwise.*

Scope: Conversion of a vacant shell to a business office headquarters. Business occupancy classification, total occupant load of 25 occupants, and modern style design.

1. **Concepts –** These prompts generated high-level architectural ideas and visual themes for the office space.

Modern Office Headquarters Prompt

"Design a modern office headquarters inside a strip mall with separate zones for a CEO office, sales offices, a unisex restroom, a break room, storage, a modern butt-glazed conference room, and a showroom. The

overall aesthetic should be minimalist, using natural materials like wood and stone, complemented by sleek glass partitions and open spaces. Include biophilic design elements with plenty of natural light."

Output



The Good: The modern office feel is there; you can clearly identify the conference room and the very spacious showroom. The minimalism is acknowledged, as are the wood and glass partitions. The biophilic design elements are represented across all images but in varying quantities.

Areas for Improvement: The strip mall aspect is not represented, nor are the sales offices, restroom, breakroom, storage, and a completely established showroom. Bearing in mind that different text-to-images (TTI) can produce different outputs, we are curious as to whether or not another TTI would output a mix of floor plans and interior renderings.

Innovative Workplace Design Prompt

"Create a detailed conceptual image for a modern office headquarters that encourages collaboration and productivity, including a flexible layout for meeting rooms, break areas, and the integration of modern technology."

Output



The Good: We like the creation of a collaged image all with different types of "collab" spaces, you can clearly see the modern aesthetic with the floating ceiling and exposed piping, floor to ceiling glass with no visually intrusive mullions. We see the technology portion acknowledged slightly with the wall mounted flatscreen in the seating area. We like the "conversation nook" and the breakroom. Nice use of the finishes.

Areas for Improvement: You cannot really see a true conference room, you actually see more offices or what appears to be offices.

2. **Massing Studies –** These prompts focus on conceptualizing the volume and massing of the office building or tenant space. *OpenArt AI Architecture Generator* was used.

Open, Transparent Massing with Glass Walls Prompt

"Generate a massing study for a modern office headquarters located in a strip mall, with a focus on transparency and openness. The exterior should feature large glass facades for the showroom and conference room, with sleek, angular volumes for private office areas. The design should be simple, clean, and efficient, with modern materials like steel and glass."

Output



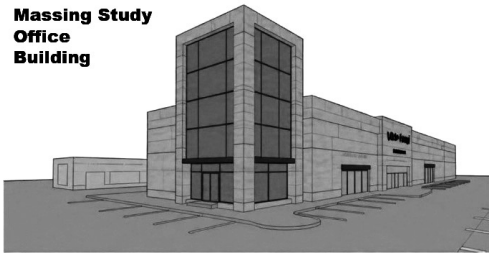
The Good: Does a decent job of showing massing and placing proper focus on the proposed design. A loose definition of "strip mall" is represented and the openness and transparency are conveyed very well. This is due to the prompt mentioning the exterior wall and large glass facades. The images easily convey visually what is glass and what is not. Everything is crisp and clean with no curves represented.

Areas for Improvement: Really difficult to get a "true" massing model feel since the images are so close up on the proposed project. It is not easy to see that the non-glass portions of the structural steel, honestly it looks more like concrete. Also, it is difficult to see the interior spaces, we are thinking may the TTI AI had to find a happy medium between the massing study (bird's eye view outside) portion and the interior space (inside the building) requests of the prompt.

Volume and Height Variations Prompt

"Describe a massing study that uses different volumes and heights to create an interesting interplay between open and private spaces in a modern office headquarters."

Output





The Good: Did a great job expressing different volumes and matching datum lines. Both images look like they are the results of renderings from a high dollar conceptual rendering program that has been on the market for 20 plus years. This looks like something that could be quickly generated to convey an idea from a prospective client or a schematic design rendering for a 15% schematic design set.

Areas for Improvement: On the early side of a schematic design and the scene is not full of life sans the white car behind the building to the right. The text is misspelled on the left and "General open space" is misspelled on the image at the right.

Building Form Exploration Prompt

"Generate volumetric studies of the office headquarters, focusing on efficient massing that separates private and public zones (e.g., CEO office, showroom, conference room)."

Output



The Good: Visually stunning and gives that architectural sketch appeal that so many expect. We were going to say the output missed the mark with the interior spaces but looking more closely at the prompt and what the TTI was instructed to focus on, we agree that the public and private zones are distinctly separate. Nice play with volume.

Areas for Improvement: Not as realistic as we would like.

3. **Interior Renderings or Visualizations –** These prompts focus on generating detailed interior scenes with realistic materials, furniture, and spatial arrangements.

Modern Conference Room with Glass Walls Prompt

"Create a detailed interior rendering of a modern conference room with butt-glazed glass walls. The room should have a long, wooden conference table with high-end chairs, integrated AV equipment, and soft LED lighting. Include modern decor elements and ensure the space feels open, bright, and collaborative."

Output



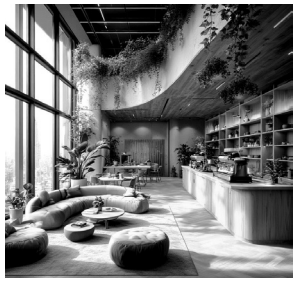
The Good: Everything is represented and accounted for. We just noticed the mention of "collaborative" in the prompt, but it is only one space so there was not much to do with that adjective.

Areas for Improvement: The request for soft lighting is not represented as strongly as we would like but we recognize that the description of the space also mentions it being bright. So there was a bit of conflict there. That is something that can be quickly remedied.

Break Room Prompt

"Visualize a relaxed and functional break room with seating, a coffee station, light wood finishes, and plants integrated into the space for a wellness-focused environment."

Output



The Good: All items mentioned in the prompt are represented, even the coffee station and other elements expected in a break room. Even the background of a major city is shown but not overpowering.

Areas for Improvement: None. If we had to choose one item, it would be the ceiling looking odd.

4. **Exterior Renderings or Visualizations –** These prompts focus on generating realistic exterior views of the building.

Courtyard and Outdoor Area Prompt

"Exterior rendering of a modern office headquarters with a landscaped courtyard or outdoor seating area. Include green walls, modern outdoor furniture, and ample lighting. The design should highlight the connection between the interior and exterior spaces, enhancing the overall office experience."

Output



The Good: Most of the images capture the full prompt.

Areas for Improvement: The first image on the left and last image on the right match one another in lack of landscaping and more emphasis on the sitting areas and hardscape.

Integration with Context Prompt

"Visualize how the office headquarters integrates with a strip mall environment in North Carolina, with a sleek, modern facade that distinguishes it from the surrounding buildings but fits the overall context."

Output



The Good: This is a really beautiful 3D proposed site plan, the ruralness of portions of North Carolina are represented as well as the new development. You can distinctly see different buildings along with parking spaces/lots lined by trees. Any arborist would love this proposed site design.

Areas for Improvement: No acknowledgement of distinguishing the buildings and the image of a strip mall was loosely interpreted.



LATENT-SPACE MODELING

Latent-space modeling refers to the process of learning a latent space, a lower-dimensional representation of data, where complex high-dimensional data (like images, sounds, or text) can be encoded into a simpler, more abstract form. These models work by mapping real-world data points (such as images or text) into this "latent space" and then manipulating or generating new data points from it.

Latent Space Modeling = The "Room of Sketches"

Imagine an AI that takes thousands of building sketches and compresses each one into a tiny dot inside a big room.

Each dot represents the essence of a building – its height, shape, style, window layout, and materials – all packed into a small code.

- When you pick a dot, the AI turns it back into a full building sketch.
- When you pick a spot between two dots, you get a sketch that looks like a blend of both buildings.
- When you pick a new spot, the AI generates a brand-new building sketch based on the patterns it learned.

Simply put, latent space is like a big room where every spot represents a different kind of building design. Moving around the room lets the AI generate new buildings without starting from scratch.

Attributes:

- **Generates new content:** These models can create new data from latent representations.
- **Unsupervised learning:** The models typically learn to map data into latent space without explicit human labeling. They identify patterns and structures in the data and use this knowledge to encode and decode information.
- **Creative generation:** The ability to explore and manipulate latent space allows for the generation of unique and creative outputs. The model can generate new data points that are like the training data but never seen before, such as new faces, scenes, or ideas.

AI Models: Models like *OpenAI* and *Stable Diffusion* use latent-space techniques to generate new content.

EXERCISES

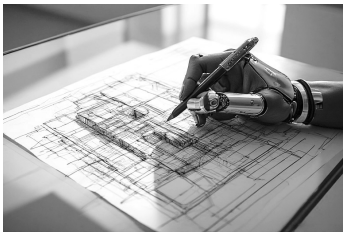
Exercise 1: We ran the following prompt with *OpenAI* "Which of his projects did Frank Lloyd Wright hate or dislike the most?" Output received (abridged): "…Larkin Administration Building in Buffalo (1904) – He admired the design concept but later resented some of the functional compromises imposed by the client…"

Exercise 2: Click the following link and go to *OpenAI* and type in the prompt below: "Who is the most well-known architect worldwide?"

You will notice that it asks for more context, all the same do you agree with the output?

Applications:

- **Image generation**: Sampling from latent space to create new images (e.g., in GANs).
- **Data interpolation**: Blending features from different data points, like blending two faces.
- **Dimensionality reduction**: Reducing high-dimensional data (like images) to a lower-dimensional representation for easier processing.



LARGE LANGUAGE MODELS (LLMS)

A large language model (LLM) is a language model trained with self-supervised machine learning on a vast amount of text, designed for natural language processing (NLP) tasks, especially language generation. The largest and most capable LLMs are generative pre-trained transformers (GPTs) and provide the core capabilities of modern chatbots.

LLMs are trained on massive datasets of text (such as books, websites, articles, etc.) to learn the patterns, structure, grammar, and meaning behind language. LLMs can generate text, complete sentences, answer questions, summarize content, translate languages, and more.

While they're traditionally associated with text generation, they are also generative models because they can create new, coherent text based on given prompts.

GPT (Generative Pretrained Transformer) models like GPT-3 and GPT-4 are state-of-the-art LLMs capable of generating text in response to prompts, completing text, and answering questions.

GPT-3 can generate essays, poems, code, and even answers to questions by understanding the statistical properties of language and predicting the next word or phrase.

BERT (Bidirectional Encoder Representations from Transformers): typically used for tasks like sentiment analysis, question answering, and other classification tasks.

Attributes:

- **Generates new content**: LLMs generate text that has never been seen before (even though they're based on training data).
- **Creativity**: They can write stories, craft poetry, or solve complex problems by generating new text based on context.
- **Probabilistic generation**: The model predicts the next word in a sequence based on patterns it has learned, generating new sentences, paragraphs, or entire articles.

AI Models: LLMs like GPT-3, GPT-4, and BERT are designed to understand, generate, and manipulate human language.

EXERCISES

Exercise 1: If you input the text " Why do architects need to be familiar with AI?," We used GPT-4 and received the following output:

"Architects need to be familiar with AI because it is changing how buildings are designed, analyzed, and delivered.

AI helps generate design options, analyze performance (energy, daylight, cost), and automate repetitive tasks, allowing architects to focus more on creativity and decision-making.

It also supports sustainable, data-driven design and improves collaboration with engineers and clients. Understanding AI ensures architects remain relevant, efficient, and ethically responsible as the profession evolves."

Exercise 2: Go to GPT-4, and type in the prompt below:
"How long does it take to develop an AI usage policy for a small to medium sized architecture firm?"

AEC ANALOGIES FOR LLMS

For Architects – "The Intern Who Has Read Every Design Book"

Imagine you have an intern who has read every architecture book, magazine, spec sheet, website, and design guideline on the planet.

They've seen so many drawings, narratives, and design discussions that they start recognizing patterns – how architects describe space, style, form, and intent.

Now when you ask:

- "Write a design narrative,"
- "Describe a façade concept,"
- "Summarize the program,"

They can instantly create organized, thoughtful text because they've learned how architectural language works.

That's an LLM – it generates text using patterns it learned from massive amounts of language.

For Engineers – "The Assistant Who Has Read Every Technical Manual"

Picture an engineering assistant who has read every structural, mechanical, electrical, and civil engineering document: codes, specs, textbooks, manuals, calculations, diagrams, and reports. Because they've absorbed so much information, they understand how engineers talk – precise, technical, and logical.

Ask them to:

- explain a concept,
- outline a system,
- summarize a calculation,
- or write part of a report –

and they can produce it instantly based on the patterns they've learned.

For General Contractors – "The Foreman Who Has Read Every Project Document Ever"

Imagine a foreman who has read every schedule, RFI, submittal, daily log, safety manual, and project spec ever created. They know how construction information is usually written – short, clear, and practical.

So, when you ask:

- "Draft a site instruction,"
- "Write a safety reminder,"
- "Summarize today's work,"
- "Explain a sequencing step,"

They can immediately produce it because they've learned the patterns behind construction communication.

For Inspectors – "The Notebook That Has Every Inspection Report Ever Written"

Imagine a magical notebook that contains every inspection report, code reference, violation example, and safety guideline ever written.

It doesn't memorize all of it – it learns the patterns of how inspectors describe issues, cite codes, and write recommendations.

When you ask it to:

- describe a violation,
- summarize a site visit,
- explain a code in plain language,
- or draft a corrective action –

It produces professional text instantly based on those learned patterns.

Applications for LLMs:

- **Text generation**: Writing essays, articles, or even creative stories.
- **Chatbots**: Conversational AI that can respond to user queries.
- **Language translation**: Automatically translating text between languages.
- **Summarization**: Condensing long articles or documents into shorter summaries.

IN SUMMARY

- **Text-to-Image**: Generating images from textual descriptions.
- **Latent-Space Modeling**: Learning and manipulating compressed, abstract representations of data (latent space) to generate new samples.
- **Large Language Model (LLM)**: AI models trained on massive text datasets to understand and generate natural language, capable of tasks like text completion, translation, and summarization.

Generative AI techniques have revolutionized creative and professional workflows across multiple industries and professions.

This concludes Part 2 of the course.

Next up is your Part 2 Quiz!

PART 2 – GENERATIVE AI PROMPTING STRATEGIES, TYPES, AND EXERCISES

KNOWLEDGE CHECK (5 QUESTIONS)

1. **What is the key characteristic of a Zero-Shot prompt?**
   A. It provides examples for the AI to follow
   B. It defines the AI's role and constraints
   C. It is clear, concise, and does not include examples
   D. It asks the AI to solve a problem in multiple steps

2. **Which prompting strategy involves assigning a persona or role to the AI?**
   A. Contextual prompting
   B. Role prompting
   C. Chain of Thought prompting
   D. Step-Back prompting

3. **What is the purpose of the "Chain of Thought" (CoT) prompting strategy?**
   A. To provide multiple examples for the AI to follow
   B. To break down complex problems into smaller, logical steps
   C. To define the AI's role and constraints
   D. To generate multiple outputs and select the best one

4. **Which of the following is an example of a Text-to-Image AI model?**
   A. GPT-4
   B. BERT
   C. Stable Diffusion
   D. OpenAI Codex

5. **What is the primary function of Latent-Space Modeling in Generative AI?**
   A. To generate text based on learned language patterns
   B. To create images from textual descriptions
   C. To encode and manipulate data in a lower-dimensional abstract space
   D. To provide step-by-step reasoning for complex problems

You made it to the finish line!
This concludes Part 2 of the course.
Continue to Part 3.

PART 3 – GENERATIVE AI FOR AEC: AI FOR AUTOMATION AND BUSINESS EFFICIENCY

Learning Objective No. 3:
Identify Generative AI tools and their use for AEC related tasks.



AEC professionals and firms can use Generative AI to streamline production, reduce errors, accelerate decision-making, and more as there appears to be no limits when it comes to AI. Remember to always review anything AI generated prior to its release.

TOOLS

TEXT TO IMAGE (TTI) AI

AI Models: Models like Stable Diffusion, DALL·E 2, Google Gemini (also an LLM), and MidJourney.

Text-to-image AI uses for AEC professionals:

Architects

1. Conceptual façade design visualization.
2. Interior layout exploration from programming requirements.
3. Landscape and site design concepts from prompts.
4. Material and finish visualization for client presentations.
5. Mood boards or style concepts for design meetings.
6. Historical or futuristic building style simulations.
7. Visualization of sustainable design features (green roofs, solar panels).
8. Marketing renderings for proposals and portfolios.



Figure 3.0. Solar Panels on a Single Family Residence © Perchance.org



Figure 3.1. Visualization of a green roof located in the downtown area of a major city © Perchance.org

Inspectors

1. Simulating potential code violations for training purposes.
2. Visualizing common safety hazards from descriptions.
3. Creating inspection scenario examples for staff education.
4. Generating imagery for fire safety, egress paths, or emergency situations.
5. Illustrating environmental risks (flooding, erosion, etc.) from site descriptions.
6. Creating before-and-after visuals of corrections or repairs.
7. Virtual inspection walkthroughs using AI-generated environments.
8. Producing illustrations for inspection reports or public awareness campaigns.



Figure 3.2. Environmental risks in high flood areas illustrated © Perchance.org

Engineers

1. Visualizing structural systems from text prompts.
2. Exploring different bridge or truss configurations.
3. Illustrating infrastructure in urban planning projects.
4. Generating diagrams for presentations or client approvals.
5. Communicating engineering ideas visually without full CAD models.

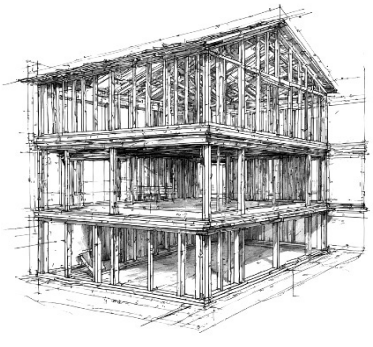


Figure 3.3. Residential framing for a 3 story SFR © Perchance.org

General Contractors

1. Simulating on-site safety hazards or best practices.
2. Creating visuals for client progress updates.
3. Communicating sequencing of multi-trade workflows.
4. Producing marketing visuals for new projects or bidding proposals.

FREE AND PAID TEXT-TO-IMAGE TOOLS

FREE

1. **Stable Diffusion Online** – "Stable Diffusion is a latent text-to-image diffusion model capable of generating photo-realistic images given any text input, cultivates autonomous freedom to produce incredible imagery, empowers billions of people to create stunning art within seconds."
2. **PerChance** – "Perchance is a platform for creating and sharing random generators."
3. **Playground AI** – "Playground AI is an online AI-powered image generation tool that creates images from text prompts or existing images. The platform provides image-to-image capabilities, styles, filters, and refinement options."
4. **BlueWillow** – "From logos and characters to digital artwork and photos, just describe the image you want and our AI image generating tool will create the perfect graphic for your project."
5. **LimeWire AI Image Generator** – "LimeWire's free AI image generator brings your ideas to life within seconds. Simply enter your text-to-image prompt and transform your creative ideas into images. With the power of our AI Image generator, the possibilities are truly endless."
6. **Hugging Face Spaces – Text-2-Image Collection**– Includes a variety of Stable Diffusionbased models that you can run in-browser (plus different model versions).
7. **Midjourney** – AI image generator, paid subscription (free to use through Meta).

PAID

1. **Midjourney** – AI image generator, paid subscription (free to use through Meta).
2. **Stability AI (Dream Studio)** – "Stability AI is unlocking the power of open-source generative AI to expand human creativity. We build world-class models that are accessible, adaptable, and designed to empower creators, developers, and enterprises everywhere."
3. **NovelAI** – "Play with your own imagination using an interface tailored towards making generating imagery simple and fast."
4. **Adobe Firefly** – Generate images, video, audio, and designs using top AI models from Adobe, Google, OpenAI, Runway, and more."
5. **Imagiyo AI** – "Create stunning and unique images with ease using our AI image generation."

LATENT SPACE MODELING AI USES FOR AEC PROFESSIONALS

Architects

1. Generating building massing variations

AI explores different points in latent space to produce dozens of massing options that meet site, height, and density constraints.

Massing Studies for a lot in Kansas City, Missouri

Façade style blending



Fig 3.4. Massing Options for a lot in Kansas City, Missouri © Open AI chatgpt.com

By interpolating between points – e.g., "brick warehouse" and "glass tower" – the AI creates hybrid façade options.



Figure 3.5. Facade style blending between a brick warehouse and glass tower © Stable Diffusion



Figure 3.5.1. Facade style blending between a brick warehouse and glass tower © Stable Diffusion

Interior design mood variations

Latent space lets AI produce multiple lighting, material, or furniture styles from one base concept.



Figure 3.6. Interior Design Mood Board © Open AI chatgpt.com



Fig 3.7. Interior Design Mood Board © Open AI chatgpt.com

Engineers

1. **Structural system exploration**
   AI generates variations of truss patterns, column grids, or framing layouts by sampling structural latent space.
2. **MEP routing concepts**
   Latent-space models create early HVAC or plumbing routing suggestions based on thousands of learned layouts.

3. **Failure scenario simulation**
   AI generates visualizations of bending, cracking, or buckling by sampling latent patterns of known failures.

General Contractors

1. **Site logistics alternatives**
   AI produces different staging, crane locations, and material yard layouts by moving through latent space.
2. **Phasing and sequencing visuals**
   Latent-space timelines help generate multiple construction sequence images from one baseline plan.
3. **Safety scenario illustrations**
   Contractors can generate visuals of potential hazards (fall risks, blocked exits) based on safety latent patterns.

Inspectors

1. **Before-and-after remediation images**
   Interpolating between two points shows unsafe → corrected conditions.

Urban Planners

1. **Neighborhood massing blends**
   AI blends urban forms (rowhouses → mid-rise → high-rise) by traversing latent space.
2. **Landscape + architecture integration**
   Latent models generate coordinated site plans where terrain, planting, and building forms naturally match.
3. **Parking and circulation layouts**
   AI samples learned circulation patterns to suggest parking lot or road configurations.
4. **Climate-adaptive design concepts**
   AI generates building/site configurations suited for heat, snow, or flood conditions based on learned patterns.

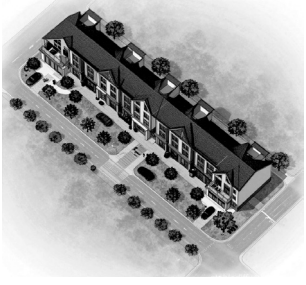


Figure 3.8. 3D Aerial of Proposed Site Plan for a Townhome Development © Stable Diffusion

FREE AND PAID TEXT-TO-IMAGE TOOLS

FREE & PAID

- OpenAI
- Stable Diffusion

LARGE LANGUAGE MODELING (LLMS) USES FOR AEC PROFESSIONALS

Architecture (AEC Design)

1. **Exercise 1: Concept Development & Design Ideation**

Converting a transcribed telephone call from a quick conversation with a very busy and high-dollar prospective client into a building program and project approach.

The Prompt We Used: "Hey I'm sorry I can't give you more time, but I wanted to make sure we had this call. So, we basically want a retail store that caters to middle aged women with no kids. The location is downtown; our biggest concerns are safety and parking. There are numerous parking garages around, but we cannot afford to validate for all of the garages. The space is not that large, maybe like 2500 square feet, and we just need space for retail, the cash wrap, storage, an office, 2 or 3 fitting rooms, and a unisex bathroom if we can keep the occupant load under 100. let me know what you think talk to you soon." We are an architecture firm, provide a building program and project approach for this project in a table format and be brief

LLM Output (GPT-4) ***we added the color*****:**

Building Program (Approx. 2,500 SF)



Figure 3.8.1 Busy prospective client on the phone © Perchance.org

SPACE	APPROX. SF	NOTES / CONSIDERATIONS
Sales Floor	1,450	Clear sightlines for safety, flexible fixtures, welcoming layout for middle-aged clientele
Fitting Rooms (2–3)	220	Near sales floor, generous sizing, good lighting, seating/hooks
Cash Wrap / POS	150	Visibility to entry + sales floor for security
Storage / Back of House	300	Inventory, deliveries, seasonal stock
Office	150	Admin, staff use, visual connection to store preferred
Unisex Restroom	130	Single-user to support low occupant load
Circulation / Walls	100	Efficient planning to maximize retail area
TOTAL	**≈ 2,500 SF**	Target occupant load < 100

Project Approach

PHASE	KEY ACTIONS
Site + Code Review	Confirm occupant load, restroom requirements, egress, ADA, and local retail code constraints
Safety Strategy	Maximize transparency, lighting, passive surveillance, controlled entry, CPTED principles
Parking Strategy	Wayfinding signage, partnerships with 1–2 nearby garages (non-validated), staff parking plan
Space Planning	Optimize small footprint, flexible merchandising, minimize back-of-house area
Design Development	Brand-driven interior, warm materials, comfortable fitting rooms, clear circulation
Permitting + Coordination	Early AHJ coordination to maintain unisex restroom and occupant load goals

Now we took this same prompt and placed it into Google Gemini

LLM Output (Google Gemini) *we added the color*:

It sounds like you have a clear demographic and some specific urban constraints to navigate. For a 2,500 sq. ft. space, staying under an occupant load of 100 is very doable (usually calculated at 30–60 sq. ft. per person for retail), which will simplify your life regarding egress and plumbing requirements.

Here is a streamlined building program and project approach tailored for your client's needs.

Building Program

SPACE	ESTIMATED SQ. FT.	KEY FEATURES & REQUIREMENTS
SALES FLOOR	1,500 – 1,700	Open plan; high-end lighting; focus on security and sightlines.
FITTING ROOMS	150 – 200	2–3 oversized stalls; high-quality mirrors and "flattering" lighting.
CASH WRAP	100 – 150	Point of Sale (POS); integrated security/ camera monitors; wrapping station.
BACK OF HOUSE/ STORAGE	300 – 400	Inventory shelving; receiving area; kitchenette nook for staff.
PRIVATE OFFICE	100 – 120	Desk space; secure file storage; window to sales floor for oversight.
UNISEX RESTROOM	60 – 80	ADA compliant; high-end finishes to match the brand aesthetic.
CIRCULATION/ WALLS	100 – 150	Efficient flow to maximize "selling" square footage.

Project Approach

PHASE	STRATEGY & FOCUS
1. SITE & CODE ANALYSIS	Verify occupant load to ensure single-exit/ unisex bathroom compliance. Analyze proximity to the most "secure" feeling parking garage.
2. SECURITY-FIRST DESIGN	Implement "Defensible Space" principles: clear sightlines from the cash wrap to the entrance and no "hidden" corners in the sales floor.
3. PARKING MITIGATION	Since you can't validate everywhere, design a digital "Parking Guide" for the store's website/app to direct clients to the safest, closest garages.
4. INTERIOR CONCEPT	Create a "Sanctuary" vibe– sophisticated, quiet, and clutter-free– to appeal to the child-free, middle-aged demographic.
5. LIGHTING & TECH	Use smart lighting for safety after dark and integrated security systems (EAS gates) that don't look overly industrial or intimidating.

EXERCISES – A TALE OF TWO LLMS

Comparing the output of both LLMs you will notice the following:

- **Building Program**
- **Occupant Load:** They both repeat what the prospective client said was their goal but only one LLM mentions the occupant load factors of 30-60 square feet per person.

Let's take it a step further, if you consult the 2024 NCSBC: BC (North Carolina State Building Code: Building Code) and go to Chapter 10> Table 1004.5. You will see that the occupant load factor for Mercantile use is ***60 gross square feet/per person***. The LLM was somewhat accurate, and this is where it is important to use your professional judgement to verify the output information. 60 gross sf/pp is the correct factor.

Now if you are familiar with the code then having this information immediately at your fingertips during the call can help you quickly determine a rough estimate of how many occupants you will have.



Figure 3.9 Mercantile Use (not occupancy classification) OLF = 60 gross sf/pp © Perchance.org

- **Square Footage:** They both acknowledge the square footage limitation but only one LLM gives a total sum of 2,500 SF in the program confirming its accuracy, while the other gives a range with no total sum.
- **Notes:** Both LLMs account for the programming requirements and take note of the number of fitting rooms mentioned by the prospective client. One LLM does a slightly better job of really understanding and emphasizing the importance of safety by mentioning "integrated security/camera monitors" at the cash wrap. And an ADA compliant unisex restroom was also mentioned by one LLM and not mentioned in reference to a restroom by the other. This is important as the ADA is a civil rights law and requires it to be adhered to on all projects unless an exception or exemption is met.
- **Project Approach**
- **Site & Code Analysis:** One LLM mentions ADA but even better another mentions the single exit exception which is directly tied to the occupant load. There is also a mention of locating "… proximity to the most secure feeling parking garage." which was a concern of the prospective client.
- **Safety Strategy:** We like that both LLMs combined mentioned CPTED and Defensible Space, both principles when followed are very valuable at creating a safe space and area.
- **Parking:** Both LLMs mentioned different strategies to approach the parking problem. One LLM gives a more traditional approach while another LLM mentions phone "apps" and a digital parking guide.
- **Interior Design:** One LLM provided more detail and current language by mentioning the "vibe" the space needed to have to appeal specifically to the demographic shared by the prospective client.
- **Lighting:** Surprisingly one LLM makes no specific mention of lighting, which as we all know goes hand and hand with a secure location and space. The LLM that mentioned lighting, even mentioned EAS gates which are "Electronic Article Surveillance gates" which prevent theft of property from a retail store.



Figure 3.10 Electronic Article Surveillance Gates (EAS) at a Retail Store © Perchance.org

- **Suggestions:** One LLM suggests that the AEC professional should meet with the Authority Having Jurisdiction (AHJ) to ensure as much as possible a smooth permitting process regarding the way the occupant load was calculated and ensuring that only one unisex restroom is required. The other LLM makes mention of specific items to watch out for with the prospective client, even going so far as to recommend impact-resistant glazing at the storefront as well as tying parking validation to the dollar amount of goods purchased by the store patron.
- **Exercise 2: It is now your turn. Find past meeting minutes from a prospective client initial meeting and copy and paste them into the GPT-4 LLM and Google Gemini LLM with a directive to generate a building program and project approach.**

What were the results? Does the program resemble the program your team created? What about the project approach?

General Contractor (Construction)

2. Exercise 1: Construction Costs

What is the question every general contractor hears constantly? (even some architects oddly enough) How much will it cost to build this? And how long will it take?

So, we will use the project from earlier and for a location we will say the Southeastern United States of America, in an A+ class tenant space located in the downtown area of major city. We will ask for a rough order-of-magnitude (ROM) given the few details provided by the 3 prospective client.

For the sake of brevity, we will only showcase the output from one LLM, we invite you to enter the prompt in Google Gemini and see how similar or dissimilar they are.

The Prompt We Used: "The project location is in an A+ class tenant space located in the downtown area of a major city in the Southeastern United states of America.

The project scope is the buildout of a retail store that is 2500 square feet and has a cash wrap area, storage and an office and 2 or 3 fitting rooms with a unisex bathroom if we can keep the occupant load under 100. This is the program we received from the architect: Sales Floor, Fitting Rooms, Cash Wrap, Back of House / Storage, Private Office, Unisex Restroom, and

Circulation / Walls. We are a general contractor and want to know the cost per square foot and the total cost (rough order of magnitude). A step-by-step breakdown of how the total cost was arrived at, the escalation factor, and how long it will take from beginning to end when the certificate of occupancy is received."

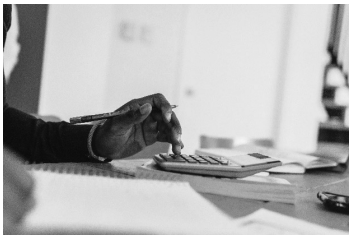


Figure 3.11. Money always matters © Pexels.com, PNW Production

LLM Output (GPT-4):

"Here's a realistic **general contractor-level rough order of magnitude (ROM) estimate** for your **2,500 sq ft retail buildout in a downtown A+ tenant space** in a major Southeastern U.S. city (e.g., Atlanta, Nashville, Charlotte, Miami, etc.). Costs vary widely by market, finishes, and landlord conditions – these numbers are *industry ranges* you can use for budgeting and proposals. (Cost Now)

1. Estimated Cost Per Square Foot

For a **full retail tenant build-out** (from shell or vanilla space) with cash wrap, storage, office, fitting rooms, basic finishes, and bathroom:

COMPONENT	TYPICAL RANGE (SOUTHEASTERN U.S.)
Mid-Range Retail TI Build-out	$150 – $320 PER SQ FT
Higher-End Retail / Custom Finishes	$320 – $420+ PER SQ FT
Average Practical Estimate for A+ Downtown	$260 – $350 PER SQ FT

This includes hard costs for walls, ceilings, floors, lighting, basic MEP (mechanical/electrical/plumbing), restroom plumbing/fixtures, partition walls for fitting rooms/office, and typical finishes. It excludes expensive custom millwork (e.g., premium display systems), tenant-furnished equipment, and inventory.

- If the landlord provides a **Tenant Improvement Allowance (TIA)** in your lease, subtract that from your cost to determine tenant-borne expenses. Typical TI in retail can range roughly **$40 – $100 per sq ft** depending on landlord negotiation and space condition. (Flavor365)

2. Total Cost (ROM)

For your **2,500 sq ft** space:

Scenario A – Mid-Range (typical finishes)
- Cost/SF: **$260**
- **Total Estimate: ~$650,000**

Scenario B – Higher-End Finishes & Systems
- Cost/SF: **$350**
- **Total Estimate: ~$875,000**

Scenario C – Premium Retail Build-out
- Cost/SF: **$420**
- **Total Estimate: ~$1,050,000**

3. Step-by-Step Cost Breakdown

Here's how the estimate is typically built up for a project like yours:

Hard Costs (70–75% of total)

CATEGORY	% OF TOTAL	ESTIMATED $ (OF $650K)
Framing & Interior Walls	~15%	~$97,500
Flooring & Ceilings	~15%	~$97,500
MEP (HVAC, electrical, plumbing)	~25%	~$162,500
Restroom & Fixtures	~8%	~$52,000
Fitting Rooms / Cash Wrap Structure	~8%	~$52,000

Soft Costs (15–20%)

CATEGORY	%	~$650K ESTIMATE
Design & Engineering	~7%	~$45,500
Permits & Inspections	~4%	~$26,000
Contractor Overhead & Profit	~10%	~$65,000

Contingency (5–10%)

Allowance for unknown conditions or scope changes:

- ~5 – 10% of total project → **$32k–$65k**

Note: Tenant allowance, furniture/fixtures/equipment (FF&E), and inventory are separate and not included here.

4. Escalation / Market Factors

Construction pricing is rising nationally due to labor shortages, supply volatility, and metropolitan demand. Expect an **annual escalation factor of ~3–6%** on base pricing if your project starts >6–9 months after current pricing. This is a general trend observed industrywide. (Cost Now)

5. Typical Timeline (From Received Certificate of Occupancy)

Here's a step-by-step schedule:

A. Pre-Construction Phase

- **Architectural design & coordination**: 2–4 weeks
- **Permit submission & review**: 3–6 weeks*
  (*Local authority reviews can vary widely by jurisdiction*)

Pre-construction total: ~5–10 weeks

B. Construction Phase

- **Demolition (if required)**: 1–2 weeks
- **Rough-in MEP**: 2–4 weeks
- **Interior partitions & framing**: 1–3 weeks
- **Finishes (flooring, ceilings, painting)**: 2–4 weeks
- **Restroom and fixtures installation**: 1–2 weeks
- **Inspections and final punch walk**: 1–2 weeks

Construction total: ~8–14 weeks

Total Timeline

~**13 – 24 weeks** (3–6 months typical from CO to final turnover) assuming no major redesigns or permit delays.

(Hartford Building Co.)

Notes for Your Negotiations

- **TIA negotiation matters** – higher TI significantly reduces tenant cash outlay. (Flavor365)
- **Market conditions vary by city** – NYC or Miami may be at the high end; many Southeastern cities fall closer to Mid-Range. (Cost Now)
- **Landlord-provided shell condition** (shell vs. vanilla) changes costs dramatically. (jaacontractors.com)
- **Contingency is required** – always hold 5–10% for unforeseen conditions.

If you want, I can tailor this estimate more specifically with **finish level assumptions**, **landlord allowance scenarios**, or break the costs down into **hard vs soft vs GC fee categories** for your internal proposals. Just tell me your priorities!"

Observations

You notice how with what little information the LLM still provides you with a very detailed breakdown. The output ensures that it is understood that the numbers used are industry ranges. Also it assumes the worst-case scenario, that the space is currently in a shell or white box status versus being a retail space currently.

In addition, mention is made of the landlord and what role they play in the calculation of the costs. No mention was made of this in the prompt mind you. What is really great is how the LLM holds itself accountable and cites its sources (in the form of a weblinks), this allows you to execute your professional judgement and see if what details are found at the various websites are legitimate.

- **Exercise 2: It is now your turn again. Find a recently completed project and write a prompt with all the information needed to calculate total construction costs as accurately as possible.**

  Next, input this information into GPT-4 LLM and Google Gemini LLM with a directive to provide you with the total construction costs using the year the project was started and to direct the LLM to provide a step-by-step breakdown.

  What were the results? Did the LLMs come close to what your total construction cost was? What was similar and what was different?

AI Models: LLMs like GPT-3, GPT-4, Google Gemini and BERT are designed to understand, generate, and manipulate human language.



HOW AI IS CHANGING THE AEC INDUSTRY

Time is money. Thanks to Generative AI the time-consuming tasks can be addressed by AI and all that is left for the AEC professional to do is exercise their professional judgement against the output, look for any hallucinations and irregularities, et cetera. Here are ways that the AEC industry is already changing. See below:

Automating Time-Consuming Tasks

1. **Automated code compliance checks**

   AI scans drawings/models for ADA, fire safety, egress, and zoning compliance, flagging issues instantly. Mind you, you will have to confirm its accuracy and exercise your professional judgment (more about that in Part 4).

   "InQI today announced the official release of Codes.IQ, the first AI-native foundation-level code compliance engine designed specifically for architects, designers, and builders. Codes.IQ debuts exactly two years after InQI filed its foundational patent, a milestone that marked the company's long-term mission to redefine how AI can automate the design-to-permit lifecycle across the built environment"

   – Street Insider

2. **Automatic quantity takeoffs**

   Systems extract material quantities from BIM models without manual measurement.

   "BIM EstiMate harnesses the power of AI and ENG's extensive project history to deliver accurate and timely estimates. To achieve this, we used insights from thousands of estimates completed at ENG, categorized by Building Type, Trades, Total Area, and Level of Development (LOD). Then, using this comprehensive dataset, we trained an advanced AI algorithm capable of predicting BIM services costs with a high degree of accuracy."

   – ENGBIM

3. **Automated drafting & documentation**

   AI generates plans, sections, details, and schedules from a single prompt or conceptual model.

   "Our intuitive platform allows you to turn your vision into reality with just a few clicks. Whether you're planning a cozy studio or a sprawling estate, our AI technology can generate detailed floor plans tailored to your preferences and spatial requirements. Simply input your desired dimensions, style, and special features, and watch as our system crafts a comprehensive layout that maximizes both aesthetics and functionality."

   – Planner5d

4. **Model cleanup and standardization**

   AI fixes naming conventions, fills missing metadata, and organizes BIM elements to office standards.

5. **Automated submittal and RFI creation**

   AI reads specifications and models, then drafts initial RFIs or submittal logs to reduce admin load.

"…Procore Agent Builder allows customers to automate workflows by building custom AI agents to meet the unique needs of their business. Now in open beta and available to all customers, this solution enables teams to create agents from scratch using natural language prompts. Users can also leverage a collection of pre-built Procore Agents – like the RFI Creation Agent, which instantly generates RFI content and searches project documents for answers, reducing the time it takes to get critical information from days to seconds, preventing costly delays on the jobsite. In addition, the Daily Log Agent can help automate jobsite reporting, ensuring real-time, accurate documentation needed to manage progress, resources, and compliance…"

– ProCore

1. SPECIFICATION WRITING AUTOMATION

Specification writing is a very important and time-consuming task for any AEC firm. Using Specifications writing software plus Generative AI Workflows allows you to reduce that time. The goal would be to find an effective and efficient balance between AI generated specifications and human generated specifications.

What AI Can Automate

- First-draft specification sections (CSI-based)
- Editing office master sections
- Comparing Specifications writing software to project-specific requirements
- Tracking changes between versions
- Summarizing conflicts across consultant specifications
- Extracting requirements from manufacturer product sheets and placing them into the specifications

Typical Workflow

1. Gather Inputs

- Specifications writing software section
- Office standard specification
- Manufacturer product data sheets
- Project requirements

2. Feed to Generative AI with a structured prompt:

"Combine the Specifications writing software section and our office master into a clean project-specific section. Highlight deviations, missing info, and items needing designer confirmation." And then copy and paste in the "Specifications writing software" section and the "Office Master"

Real World/Real Time Benefits

- "AI can streamline specification creation by establishing a 'brilliant baseline,' automating the project manual's table of contents (TOC) and generating pre-selected options based on project requirements… Since around 80% of specification content is often consistent across projects, AI can streamline the creation of baseline documents… saving time and reducing time-consuming tasks." *– How AI can transform your specifications, AIA.org*
- "AI ensures that approved clauses and preferred language are used consistently, regardless of which team member is drafting the agreement… AI can enforce organizational standards automatically, preventing the use of outdated or non-preferred language." *– Icertis*
- "AI provides project-wide access to a Specification Q&A tool that gives instant, direct answers from the documents… reducing misinterpretations and errors caused by an inability to find information." *– AllGanize*

2. CODE + ZONING SUMMARIES

ICC Model codes (like the IBC, IMC, IPC, IFC, etc.), ADA, NFPA, local zoning code, et. cetera

What AI Can Automate

- Summaries of applicable IBC sections
  - Copy and paste the IBC section and request a summary
- Occupancy classification analysis
  - If you ever have a question as to which occupancy classification your project is, place both competing occupancy classification definitions into AI and then type in, in a very detailed way, the scope of work of the project. If you want to take it a step further, tell AI the state the project is in (if in the US) and add a link to the local ordinance of the jurisdiction being worked in just in case there are any nuances. For example, in some jurisdictions an A-2 with 49 or less occupants is a Business occupancy classification but in another AHJ it is a Mercantile occupancy classification.
- Egress requirements (widths, distances, exits)
  - This would be a quick way to learn your minimums and maximums while drafting a conceptual design. Be very careful with this and always have a human confirm that what is being stated is accurate.
- ADA / accessibility summaries
- Zoning envelope extraction (FAR, height, setbacks)
  - Feeding a zoning ordinance into AI, can be as simple as adding a link and then asking your question.
    - For example, we went to ZoningBot.com where it "…lets residents and planning staff chat with their zoning ordinance. Look up zoning by address, ask follow-up questions, and get clear answers backed by your city's code."

This is a much more exciting and efficient way to quickly obtain your limitations, especially for feasibility studies.

Typical Workflow

1. Input site address, occupancy, and proposed use.
2. Upload zoning ordinance excerpts or IBC sections. Or depending on the AI being used provide the website URL.
3. Request structured outputs:
   - "Zoning envelope summary"
   - "Code path diagrams"
   - "Applicable sections + exceptions"
4. AI returns a formatted, checked version that humans verify. (mission critical step)

"Need quick insights? Review the brief AI-powered overview of your doc. Then select a suggested question or ask your PDF any question to streamline document research and analysis."

– Adobe PDF

3. COST-ESTIMATING FIRST PASSES

(Rough Order of Magnitude (ROM) pricing, feasibility studies, conceptual budgets)

What AI Can Automate

- Rough-order-of-magnitude (ROM) cost estimates
- Breakdown by trades, CSI divisions, or building systems
- Cost-driven design option comparison
- Historical cost data analysis
- Assumption sheets for estimators to refine

(Note: Always verified by a qualified cost estimator.)

"While traditional estimating methods rely on time-intensive manual work with the potential for error, AI tools can produce estimates faster and more accurately."

– ConstructConnect

4. RFI + SUBMITTAL AUTOMATION

What AI Can Automate

- Draft RFI responses
- Extract relevant sheets/details
- Identify conflicts between drawings + specifications
- Suggest standard approval/denial language
- Create tracking logs + summaries
- Draft Architect Supplemental Instruction / Proposal Request narratives

Typical Command

"Based on sheet A5.1 detail 03 and Section 07 27 00, draft an RFI response including required coordination notes and confirm if this requires an ASI."

5. MARKETING + PROPOSAL AUTOMATION

(Request For Proposal responses, project write-ups, resumes, graphics support)

What AI Can Automate

- •Project descriptions tailored to the Request For Proposal
- Firm qualifications summaries
- Team member resumes (formatted to Owner requirements)
- Cover letters & executive summaries
- Proposal narratives (approach, innovation, sustainability)
- Draft schedules & work plans
- Past project comparisons

Workflow

1. Upload the Request for Proposal (RFP) + the firm's boilerplate material.
2. Ask AI to:
   - Extract requirements
   - Create a compliance matrix
     1. Another step would be analyzing the RFP using AI against the firms' Go / No Go determination document
   - Draft tailored proposal sections

Real World/Real Time Benefits

- Faster turnaround on proposals
- Reduced staff burnout during pursuits
- More consistent messaging across submissions

"AI-powered automation can drastically reduce the hours spent on crafting proposals. That means more time to focus on closing deals, driving growth, and staying competitive… you can automate the proposal writing process while maintaining top-notch quality and personalization." – DataGrid

6. SUMMARY: WHERE AI DELIVERS THE HIGHEST RETURN ON INVESTMENT (ROI) IN AEC AUTOMATION

TASK	WHY IT WORKS
Specification writing	Highly repetitive, structured data
Code + zoning summaries	Pattern-based interpretation and formatting
RFI responses	Relies on extracting information from drawings and specifications
Marketing proposals	Standardized structure and reusable content
Cost-estimating first passes	Ideal for early conceptual direction

7. Integration Strategy for Firms

To adopt these automations successfully do the following:

A. Standardize Inputs

- Office master specifications
- Template narratives
- Code summary formats
- Proposal boilerplates

B. Centralize Prompts

Create a shared library:

- **AEC Specification-writing prompts**
  - Project Information & General Conditions
    - Prompt: "For the architect's specifications for XYZ firm write an introductory section that outlines the project, including the name, location, and scope of work. Provide the names of the parties involved (owner, architect, contractor) and state the general conditions, such as compliance with North Carolina building codes and environmental regulations." Depending on your approach you can have AI pull from your knowledge base or just copy and paste the information it requires.
  - Summary of Work (Division 1)
    - Prompt: "In Division 1, Section 01 10 00 – "Summary of Work," describe the overall scope of the project, including key milestones, site conditions, and any specific requirements, such as permits, environmental considerations, or stormwater management in compliance with North Carolina laws, specifically for the jurisdiction of Raleigh, North Carolina."
- **Code interpretation prompts**
  - Prompt" Would a cafe with less than 30 occupants be considered a business ibc"



Figure 3.12. A lovely couple enjoying a meal on the back deck of a cafe © Photo by David Crypto, Pexels.com

    - The output from Google's "AI Overview" was the following with multiple supporting links: "Yes, under the International Building Code (IBC), a cafe with an occupant load under 50 (like under 30) is often classified as a **Group B (Business) Occupancy**, even though it serves food, because it's a smaller assembly space accessory to the main business, avoiding stricter Assembly (Group A) rules. This "50-person rule" reclassifies small coffee shops, bakeries, or pizza places with limited seating into the less stringent Business category."
  - Prompt: "I have a client who wants our architecture firm to design a retail store in downtown Providence, Rhode Island, the space is 5,000 square feet with 2,000 square feet for storage how many occupants can it hold per the applicable codes of that jurisdiction? Give us a short one paragraph summary."

        - LLM Google Gemini output:

          "For your 5,000 square foot retail space in Providence, Rhode Island, the maximum occupant load is calculated using the Rhode Island-adopted **2021 International Building Code (IBC) Section 1004.5**, which requires separate calculations for distinct functions: the **3,000 sq ft sales area** (5,000 total minus 2,000 storage) utilizes the Mercantile OLF of 60 Gross sq ft/person for **50 occupants** (3,000/60), while the **2,000 sq ft storage area** utilizes the Storage OLF of 300 Gross sq ft/person for **7 occupants** (rounding up 2,000/300 = Approx 6.67); therefore, the total maximum calculated occupant load for the space, which is the figure required for designing the means of egress and life safety systems, is **57 people**."
    - **As stated previously, we fact checked everything starting with the applicable model code and edition and then the specific code sections cited to ensure occupant load factor accuracy. This is very convenient for random prospective client calls. Remember that all AI output must be qualified by a human design professional prior to use or release.**
- **RFQ Proposal prompts**
    - Prompt: "We are an architecture firm submitting a RFQ proposal. What is the best approach to win a roof replacement public project in Boise, Idaho? What standard forms do we need to complete? Provide response in the form of one short paragraph with any pertinent links"
        - LLM Google Gemini output:

          "The best approach to win a public RFQ for a roof replacement project in Boise, Idaho, is to focus on demonstrating superior, relevant qualifications under the state's Qualifications-Based Selection (QBS) process (Idaho Code § 67-2320). Your submission must clearly outline your specific experience with similar public or commercial roofing projects, particularly those involving public works, historic properties, or complex membranes, while highlighting the qualifications of the key personnel who will be on the project team. Since you are an architectural firm, you will primarily need to provide a Statement of Qualifications (SOQ), and while the specific forms depend on the procuring agency (e.g., City of Boise, Ada County, or Idaho Division of Public Works), they frequently require forms detailing firm experience, personnel résumés, and references, often using standard formats similar to the Idaho Division of Public Works documents available on their website.

          Idaho Division of Public Works Forms & Documents:
          https://dpw.idaho.gov/docs-forms-guides/

          Would you like me to search for a sample City of Boise or Ada County Request for Qualifications (RFQ) document to identify their standard submittal forms?"

C. Human-in-the-loop QA

AI output must be validated by a design professional, i.e. licensed architect or licensed engineer. (This is a Mission Critical Step)

1. Specification Sections (CSI Format Editing with LLMs)

AEC firms commonly use GPT-4o with structured prompts to merge Specifications writing software sections, office masters, and project-specific requirements. This produces a clean first draft in less time than manual editing. Human specifiers are to always review for liability, code compliance, and accuracy.

Specification Person Prompt Template

"You are an expert architectural specifier with 15+ years writing CSI MasterFormat specifications for healthcare and education projects."

2. Code/Zoning Compliance Deficiency Reports & Summaries

LLMs excel at extracting and tabulating code requirements when fed current IBC/zoning text plus project parameters. (this can easily be done if you are a member of the ICC or NFPA and have access to the "Copy" function which the free public versions do not allow)

Typical Prompt

Project: Mixed-use podium building, Seattle, Washington, USA

Occupancy: R-2 above, A-2/B below

Stories: 7 total (1 podium + 6 residential)

Site address: 123 Example St (upload current Seattle Land Use Code excerpts)

Tasks for the Generative AI:

1. Code Compliance Matrix (table format) for IBC 2021 + Seattle amendments covering: allowable height/area, type of construction required, fire separation, egress, accessibility.
2. Highlight any non-compliances or exceptions needed.
3. Provide one-paragraph design narrative summary acceptable for early submittal.

Before (Manual Summary – Fragmented & Verbose)

Per IBC Table 506.2, R-2 is 11 stories / 285ft in Type IA… but Seattle limits wood-frame to 85ft… need Type III or better for podium… two exits required above 10 occupants… etc.

After (AI-Generated Clean Report – Ready for Human Verification)
(we added the colors in)

PARAMETER	REQUIREMENT (IBC 2021 + SEATTLE AMENDMENTS)	PROPOSED DESIGN	COMPLIANCE STATUS	NOTES / EXCEPTIONS REQUIRED
ALLOWABLE HEIGHT	85 ft / 6 stories for Type VA wood-frame (SMC 23.54.030)	78 ft / 7 stories total	Non-compliant	Seek height exception via Design Review
ALLOWABLE AREA	48,000 sf (Type VA, NS, 3 stories above podium)	42,000 sf per floor	Compliant	—
CONSTRUCTION TYPE	Type IIIA minimum for mixed-use podium separation	Type IIIA proposed	Compliant	2-hr podium separation required
NUMBER OF EXITS	2 minimum for floors > 10 occupants (IBC 1006)	2 scissor stairs provided	Compliant	—
ACCESSIBILITY	20% Type A units (Seattle amendment)	22% provided	Compliant	Exceeds requirement

Narrative: The proposed 7-story mixed-use building complies with IBC 2021 and Seattle amendments in all areas shown *except maximum height*, which exceeds the 85-ft limit for Type VA construction by 3 ft. A design-review departure is requested based on superior urban design and public-benefit features.

3. Proposal/RFP Narrative Language

Firms paste the RFP requirements + firm boilerplate and ask the LLM to generate tailored sections.

Typical Prompt

RFP Requirement: "Describe your firm's approach to sustainable design and provide three relevant project examples demonstrating LEED Platinum outcomes."

Firm boilerplate attached + sustainability statement attached.

Write a 400-word response in first-person, professional tone that exactly matches our firm voice (confident but collaborative). Include metrics and client names where approved.

Before (Generic Boilerplate)

Our firm is committed to sustainability. We pursue LEED certification on most projects and have achieved Platinum on several.

After (AI-Tailored Winning Language)

At [Firm Name], sustainable design is not an add-on – it is the foundation of every decision we make. We integrate passive-first strategies, life-cycle carbon analysis, and circular-economy principles from pre-design onward, consistently delivering projects that exceed client ESG goals while reducing operational costs by 25–40%.

Three recent LEED Platinum projects demonstrate this rigor:

1. Northwest Community Hospital Expansion (2023, 480,000 sf) – Achieved LEED v4 Platinum (82 points) through 100% on-site renewable energy, 62% water-use reduction via greywater reuse, and salvaged materials exceeding 20%. The owner reports 38% lower energy bills than code baseline.
2. Cascade Tech Campus (2024, 1.2M sf) – First net-zero-ready office campus in the Pacific Northwest to earn Platinum. Features include mass-timber structure reducing embodied carbon 45% vs. concrete, triple-glazed façade, and a 2.1 MW solar array. Microsoft reports 41% energy savings.
3. Riverside Mixed-Use (2022, 320 units) – Urban infill project achieving Platinum through adaptive reuse of an existing warehouse (55% embodied-carbon reduction), all-electric systems, and biophilic design that improved occupant satisfaction scores by 28% (post-occupancy survey).

These outcomes stem from our proprietary "Carbon-First Charrette" process, conducted with owners and contractors on Day 1 to lock in aggressive but achievable targets. We bring the same discipline to this project, targeting LEED v4.1 Platinum while prioritizing health, resilience, and community benefit.

4. RFI Response Drafting

Typical Prompt

Sheet A2.01 Detail 4 shows waterproofing terminating at foundation wall but Section 07 13 00 calls for continuous membrane under slab. Draft a professional RFI response proposing which detail governs, no cost/time impact, and requesting confirmation.

Before (Rough Internal Note)

The drawing and spec conflict on waterproofing termination. We think detail is correct. No extra money.

After (AI-Generated Professional Response) RFI No. 012 – Waterproofing Termination Clarification

Question: Sheet A2.01 Detail 4 depicts the sheet waterproofing terminating at the interior face of the foundation wall with sealant joint, while Section 07 13 00 Article 3.4 appears to require the membrane to extend continuously beneath the slab-on-grade. Please advise which condition governs.

Recommended Resolution: The project intent is for the waterproofing to follow the published detail (continuous under footing, turned up foundation wall, terminated with sealant). Extending the membrane continuously under the slab would require additional material and labor not contemplated in our bid. We propose proceeding per Detail 4/A2.01 at no additional cost or time. Please confirm or provide revised direction.

These real-world examples show AI delivering first-draft efficiency while preserving professional tone, accuracy, and liability awareness – provided a licensed professional always performs final review and sign-off.

You made it to the finish line!
This concludes Part 3 of the course.
Next up is your Part 3 Quiz!

PART 3 – GENERATIVE AI FOR AEC: AI FOR AUTOMATION AND BUSINESS EFFICIENCY

KNOWLEDGE CHECK (5 QUESTIONS)

1. **Which of the following is a use case for Text-to-Image (TTI) AI for architects?**
   A. Generating inspection scenario examples for staff education
   B. Visualizing structural systems from text prompts
   C. Conceptual façade design visualization
   D. Creating visuals for client progress updates

2. **What is a key benefit of Latent-Space Modeling for architects?**
   A. Generating diagrams for client presentations
   B. Exploring façade style blending and massing variations
   C. Simulating on-site safety hazards
   D. Creating visuals for marketing proposals

3. **Which of the following is an example of a Large Language Model (LLM) use case for architects?**
   A. Drafting RFI responses and tracking logs
   B. Generating building programs from client conversations
   C. Visualizing common safety hazards from descriptions
   D. Creating before-and-after remediation images

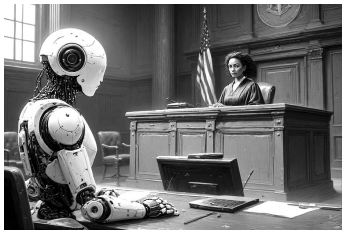
4. **What is a common workflow for automating specification writing with Generative AI?**
   A. Uploading zoning ordinances and requesting summaries
   B. Generating visuals for fire safety and egress paths
   C. Creating marketing visuals for proposals and portfolios
   D. Combining office master specifications with project-specific requirements

5. **How can AI assist in automating code and zoning summaries?**
   A. By extracting zoning envelopes and egress requirements from ordinances
   B. By generating diagrams for presentations or client approvals
   C. By creating visuals for urban planning projects
   D. By simulating potential code violations for training purposes

This concludes Part 3 of the course.
Continue to Part 4.

PART 4 – ETHICS, INTELLECTUAL PROPERTY (IP), AND THE FUTURE

Learning Objective No. 4:
Analyze the legal landscape regarding use of AI-generated content.



Lastly, we answer what the stance of the AEC industry is on AI and its use.

AI USE AND THE RESPONSE OF THE AEC INDUSTRY

ARCHITECTS ENGINEERS AND INSPECTORS

NCARB's Position on the Use of Artificial Intelligence in the Architectural Profession – Source

"…Although the ABM *(NCARB's June 2024 Annual Business Meeting (ABM))* participants' opinions were divided on how regulators should engage with AI, NCARB and its regulatory community approached consensus on several points:

- Regulators should not limit the use of technological advances that support the profession's ability to improve the health, safety, and welfare of the public.
  - It falls outside of NCARB's mission and expertise to evaluate or provide opinion on specific AI tools and their application, nor is there precedence for enforcing limitations on a tool's use.
- Any proposed regulation that addresses AI usage in practice **must ensure the licensed practitioner remains in responsible control and continues to be accountable for all technical submissions under their seal.**
- **AI is a tool – it is not a replacement for professional judgement. Regardless of AI tools used, it remains the architect's responsibility to provide services in conformance with the standard of care.**
- NCARB is committed to staying apace with the profession and to ensuring that licensure requirements consider both current practice methods and the overarching responsibility that rests with the architect.

  In evaluating perspectives from the regulatory community, NCARB plans to work with its licensing board members to further explore two areas regarding guidance and best practices for the architect's use of AI:
- Reassessment of responsible control parameters to determine whether they appropriately address the use of AI tools.
- Identification of best practices for ethical AI usage, including determining whether, when, and how the use of AI and its supporting datasets should be declared…"

– Abridged Version; Full Statement

ASME Position Statement on the Use of Artificial Intelligence (AI) for ASME – Link

"…External content is considered to be any materials produced for publication, distribution, or integration by ASME. An Author is a person creating external content; AI tools are not considered acceptable Authors. ASME requires Authors to fully report their use of AI tools, at any stage of the process of creating external content, in an appropriate place within the content itself…" *– ASME Condensed Position Statement on AI Use in External Content; Full Version*

NFPA

"The NFPA has reported the findings of its third annual industry survey conducted during the NFPA 2025 Conference & Expo in the United States.

The organisation explained that the survey provides insights into how skilled trade workers view technological change, training needs, and workforce pressures.

- According to the NFPA, **ninety-five percent of respondents said AI has a role in some part of daily job functions.**
- It stated that 31 percent of those surveyed view AI as a way to improve efficiency during labour shortages.
- The NFPA added that 39 percent believe AI could drive industry growth and help attract younger workers.
- It noted that one quarter of respondents remain sceptical of AI's role, though many still report benefits from using advanced technologies.
- The survey also found that 64 percent of participants had experienced better workflows and collaboration since adopting digital tools..." *– Article; Full Survey*

ICC (International Code Council)

ICC Evaluation Service

"Automated product evaluation streamlines many components of the certification process; decreasing the turnaround time for new building product listing reports even further. ICC-ES has utilized AI software for a number of standards to date, and will be expanded in 2021 and beyond. AI has also been utilized for application processing for evaluation service reports, for building and plumbing products. "AI software is an extremely valuable resource for ICC-ES and, in turn, our clients," said ICC-ES President Shahin Moinian, P.E. "We are excited to fully realize the potential of this AI application in the evaluation service sector and further our innovative product offerings"." – ICC Evaluation Service News Release



Figure 4.1 It is very important to know the stance of governing bodies on AI
© Ekaterina (Katrin) Bolovtsova, Pexels.com

ICC Safe

"The building safety industry is experiencing a new era of efficiency and innovation thanks to emerging technology such as artificial intelligence. The International Code Council's Digital Codes Premium®

platform has recently introduced two new code intelligence tools that harness the power of this cutting-edge technology.

The new features, ICC Premium Answers and ICC AI Navigator have been added to the Code Council's suite of innovative and easy-to-use digital solutions to help users access information faster.

The AI Navigator and Premium Answers signify a major milestone in the Code Council's Digital Transformation Strategy." *– ICC Safe, Building Safety Journal*

GENERAL CONTRACTORS

Associated General Contractors (of America)
The Construction Association

"AGC of America has released the new 2025 AI Resource Guide for Construction Professionals (members only content), a practical roadmap to help construction companies of all sizes confidently integrate artificial intelligence into daily operations." – Article

Current Professional Liability Risks

> ***"…As far as architects and engineers professional liability is concerned, Black said that the main risks are hallucinations, data privacy and confidentiality, all of which can be minimized with appropriate diligence, oversight and robust quality assurance and control. However, he added that there are also larger enterprise risks associated with the evolution of the design process enabled by AI..." – Full Article***

"…As attorneys, we have empathy skills. People don't want to sit in front of a computer and talk about really difficult, hard things. They want to look you in the eyes," Doughty explained.

AI is just a tool, and fears over being replaced may be overblown. Doughty is using the technology on a daily basis. Along with using it to edit her presentation into bullet points for experienced in-house attorneys, she uses it to draft legal scenarios.

Doughty advises not to use a person's real name because of privacy. "I also use it when I am frustrated with someone, so I draft how I really feel, then ask the AI to make it more professional," noted Doughty.

AI can quickly write an article if provided with a topic, a target audience, and a few links. The speed and accuracy are astonishing, but many believe it is difficult, if not impossible, to determine whether the copy was plagiarized. This is likely to be the subject of ongoing litigation." *– Full Article*

Construction Professionals:

"How AI impacts your PLI cover – PLI claims are often long-tail, meaning there can be a substantial gap between when an incident occurs and when a claim is made. While AI-related PII claims haven't yet emerged, these technologies are still new – and the risk of future claims cannot be dismissed. Underwriters are taking notice, increasingly asking questions around how firms are using AI and, in many cases, requesting to review any existing AI policies.

It is highly recommended that firms who are incorporating AI into their operations draw up a clear usage policy – to set out protocols, ensure human oversight, and establish accountability should something go wrong…" – Full Article

The AEC industry faces heightened exposure when incorporating AI-generated content into client deliverables or regulatory submissions. The core principle remains as it always has: the design professional (i.e. licensed architect or licensed engineer) is fully responsible for the final output or work product, regardless of the amount of AI assistance.

Key risks and Real-World implications:

- **Standard of Care Violations**: If AI introduces errors (e.g., hallucinations in code interpretations, inaccurate daylight simulations, or non-compliant details), the firm can be liable for negligence. Governing bodies view over-reliance on AI without rigorous human verification as a breach of the duty to exercise professional judgment. For example, a consulting firm issuing reports with fabricated citations from AI tools, leading to client disputes.
    - For example, in our drafting of this course we asked AI what the occupancy classification would be for an A-2 occupancy classification with an occupant load of 38 occupants in Bend, Oregon. The output we received was A-2, even after we introduced the code section which permits it to be classified as a Business occupancy classification. Again, professional judgement.
- **Insurance Coverage Gaps**: Professional liability (E&O/PL) policies may now contain "silent AI" exclusions or require disclosure of AI use during renewal.

> ***"…'Silent AI' refers to AI-driven risks that are neither explicitly included nor excluded in insurance policies, leaving room for potential coverage gaps. This ambiguity can lead to significant financial losses for insurers. Avoiding these unforeseen claims should be to be a priority for PI underwriters…" – Article***

  Risks that generative AI pose for professional service providers include liability for mistakes, data breaches and regulatory challenges. This equates to insurers adding clauses limiting coverage for AI-generated outputs, algorithmic bias, or failures in AI-assisted decisions.

  Regarding AI on the international errors & omissions market the expectation is that, should an architect or engineer (or any professional) rely on Generative AI in the delivery of their service it is understood that they are still bound to their standard of care (for architects), laws, and rules & regulations of their respective jurisdiction and/or regulatory body. Thus, the design professional providing the service would be liable if Generative AI produces erroneous outputs which are later relied upon as fact.
- **Regulatory Scrutiny and Disciplinary Action**: As mentioned previously, licensing boards (via NCARB for architects, NCEES/NSPE for engineers) emphasize that AI is a tool and in no way a substitute for licensed oversight and professional judgement.

  Submitting unverified AI content to authorities having jurisdiction could possibly trigger complaints for not meeting one's standard of care. *At the time of the drafting of this course, no board had revoked any professional's license to practice architecture, engineering, or general contracting solely for AI use/misuse.*

  But in Australia a solicitor (lawyer) was stripped of their ability to practise (sic) as a principal lawyer after using AI generated false citations and not verifying their case list.

The Crime

"…the anonymous solicitor representing a husband in a dispute between a married couple provided the court with a list of prior cases that had been requested by Justice Amanda Humphreys in relation to an enforcement application in the case.

When Humphreys returned to her chambers, she said in a ruling that neither herself nor her associates were able to identify the cases in the list. When the matter returned to court the lawyer confirmed that the list had been prepared using legal software that utilised (sic) AI. He acknowledged he did not verify the accuracy of the information before submitting it to the court.."

The Punishment

"..the lawyer had his practicing (sic) certificate varied on 19 August as a result of the investigation, meaning he was no longer entitled to practise (sic) as a principal lawyer, not authorized (sic) to handle trust money, would no longer operate his own law practice, and would only practise (sic) as an employee solicitor.

The lawyer will undertake supervised legal practice for a period

of two years, with the lawyer and his supervisor reporting to the board on a quarterly basis in that time…" – Source

- **Emerging Bodily Injury/Strict Liability Exposure**: For performance-critical outputs (e.g., AI-optimized structural grids or egress calculations), failures could lead to property damage or bodily injury claims or worse. Authorities having jurisdiction are developing legal frameworks specifically for AI. These are rules or laws that would determine who is legally responsible when AI systems cause harm or issues.
- For example, the Artificial Intelligence Task Force (an advisory committee) in California:
    - "The task force's charge is to:
        - Oversee development of AI policy recommendations;
        - Coordinate development of proposals and branch actions;
        - Develop proposals regarding use of AI in the judicial branch; and
        - Work with other government or branch entities on AI policy developments

    Because generative AI has the potential to affect the judicial branch in numerous ways, the task force decided to identify some specific issues to direct their initial focus. Those areas are:

    1. Developing a generative AI model use policy for courts, as well as other rules and guidance related to the use of generative AI for court-related work;
    2. Identifying ways that generative AI can be used to improve self-help services for court users;
    3. Evaluating generative AI's impact on evidentiary submissions in court proceedings, such as the risk that generative AI will be used to create false evidence; and
    4. Identifying the ways that generative AI might impact legal research both within the courts and by court users." – Learn More

Example of an Insurance Exclusion:

"…any insured's actual or alleged statements, disclosures, or representations concerning or relating to artificial intelligence, including, but not limited to:

a) the use, development or integration of artificial intelligence in the company's business operations;

b) any assessment or evaluation of threats, risks or vulnerabilities to the company's business or operations arising from artificial intelligence, whether from customers, suppliers, competitors, regulators, or any other source; or,

c) the company's current or anticipated business plans, capabilities and opportunities involving artificial intelligence" – Source

Mitigation:

- Mandatory "human-in-the-loop" (HITL) protocols with documented verification.
    - A great article titled "Human-in-the-Loop AI: Balancing Autonomy with Oversight" from Medium.com, excerpts below:

      Human-in-the-Loop AI is a closed-loop system where human judgment is embedded at key points in the AI lifecycle:

      Training: Humans label data, define ground truth, and correct model missteps.

      Validation: Humans evaluate model outputs, especially edge cases.

      Deployment: Humans monitor live predictions, override when necessary, and feed corrections back into the loop.

      Architecture: This cyclical integration of oversight ensures AI remains accurate, auditable, and aligned with enterprise goals.

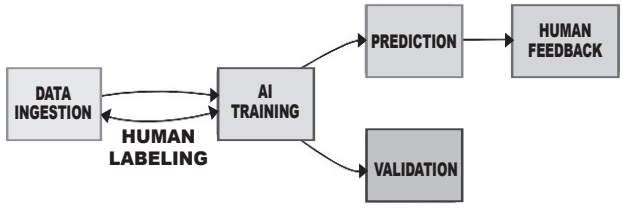


Figure 4.2. HITL Architecture Diagram © Medium.com

- **Every firm or business should have AI policies that include requiring disclosure to clients and insurers.**
    - Per Clio.com, a professional practice (in this case a law firm) AI policy should address factors including but not limited to:
        - AI ethics, including potential discrimination and bias
        - Guidelines for data collection and usage
        - Expectations for transparency
        - Data protection and cybersecurity best practices
        - Future risk assessment as AI develops
        - User experience and accessibility
        - Legal framework and industry standards
        - Governance, oversight, and adaptation
        - Employee training
        - Adaptation to new legal innovations

- **Specialized AI endorsements on PL policies**
    - Example of an Affirmative AI endorsement use in the Technology sector for Errors & Omissions Insurance – Full Article

      "An Affirmative AI Insurance Endorsement is a clause in a Tech E&O or Cyber insurance policy that expressly grants coverage for liabilities tied to AI use, development, or outputs. Common examples of covered risks include:
        - Algorithmic decision errors (e.g., hiring, lending)
        - Copyright claims from AI-generated content
        - Regulatory actions tied to automated services
        - Training data misuse
        - Model hallucinations or consumer misguidance"



INTELLECTUAL PROPERTY AND COPYRIGHT CONCERNS

Key Excerpts from Part 2 of the U.S. Copyright Office Policy on Artificial Intelligence – Full Report:

- **Human Authorship Requirement**: Copyright protection in the U.S. requires human authorship. *AI-generated material that lacks sufficient human contribution is not eligible for copyright protection.*
- **Assistive AI Use**: Using AI as a tool to assist human creativity does not affect the copyrightability of the resulting work. Human authorship remains protected when AI is used *to enhance or modify human-created works.*

- **Prompts and Copyright**: Prompts alone, even if detailed, do not provide sufficient human control to claim authorship of AI-generated outputs. *Prompts are considered instructions that convey unprotectible ideas.*
- **Expressive Inputs**: Human-authored inputs, such as illustrations or text, that are perceptible in AI-generated outputs can be protected by copyright. The protection applies to the human-authored elements and their arrangement, but not to the AI-generated elements alone.
- **Modifications and Arrangements**: Human authorship can be claimed if AI-generated material is creatively selected, arranged, or modified. Copyright protection applies to the human contributions and the overall work, but not to the AI-generated elements in isolation.
- **International Approaches**: Most countries agree that copyright requires human authorship, though some jurisdictions are exploring or have implemented sui generis rights for AI-generated works. The U.S. Copyright Office is monitoring these developments.
- **No Need for Legal Change**: The U.S. Copyright Office concludes that existing copyright law is sufficient to address questions of copyrightability for AI-generated works. Legislative changes are not recommended at this time.
- **Impact on Human Creativity**: Extending copyright protection to AI-generated works *could discourage human authorship and creativity,* potentially leading to a decline in human-created works.
- **Empowering Creators with Disabilities**: AI tools can empower creators with disabilities by assisting them in expressing their creativity. *Copyright protection remains available for works where AI is used as an assistive tool.*
- **Clarity and Guidance**: The U.S. Copyright Office aims to provide ongoing guidance and updates to clarify copyrightability issues related to AI-generated content.
- **No Sui Generis* Rights Recommended**: The Office does not find the policy arguments for additional sui generis protection for AI-generated material persuasive, as existing legal frameworks provide sufficient incentives for innovation.
    - *"Sui generis is a Latin term meaning "a special kind". In intellectual property rights discourse (IPRs) the term refers to a special form of protection regime outside the known framework. It can also be viewed as a regime especially tailored to meet a certain need." – Source
- **Monitoring Developments**: The U.S. Copyright Office will continue to monitor technological and legal developments to evaluate whether its conclusions should be revisited in the future.

Implications for AEC submissions:

- **Client Deliverables**: Firms cannot claim full copyright over AI-heavy content (e.g., concept renderings). Clients may demand ownership warranties that are now risky to give without heavy human modification.
- **Infringement Risk from Training Data**: Tools like Midjourney/ Stable Diffusion were trained on vast datasets including architectural images. Outputs resembling existing copyrighted designs (e.g., a "Zaha Hadid-style" façade) could trigger claims. While no AEC-specific infringement suits have succeeded yet, parallel cases (e.g., artists vs. Stability AI/Midjourney) show courts allowing claims where outputs are "substantially similar."
- **Regulatory Submissions**: Plans/specifications submitted to authorities having jurisdiction become public record. Using uncopyrightable AI elements weakens the firm's Intellectual Property (IP) protection if copied by others.

Best practices:

- Consider having an AI Firm Policy state that all AI outputs are viewed as "inspiration only" and have all employees sign and date said policy stating that they understand and will abide.
- Create and uphold a "human first" template for all instruments of services leaving the office, with AI being a tool used after the human generated content is created.
- Use the Liability Checklist to pair with all documents using AI that are leaving the office.

ETHICAL ISSUES

PROFESSIONAL ORGANIZATIONS IN THE AEC INDUSTRY (NSPE, AIA, ASCE, NCARB)

- **NSPE Position Statement No. 03-1774 (Sunset Date June 2026) – Source**
    - "1. Ethical and Environmental Responsibility: NSPE emphasizes the ethical responsibility of engineers and AI professionals in the design, development, and deployment of trustworthy AI systems. Engineers and AI professionals must prioritize ethical considerations to ensure that AI technologies are designed and used in ways that do not harm individuals, society, or the environment. Ethical guidelines should be at the forefront of AI development to address issues such as bias, transparency, accountability, and environmental sustainability."
- **AIA: Ethical challenges of generative AI in architectural practice – Source**
    - "…the duties required by the AIA Code of Ethics and Professional Conduct (2024 edition) involving competence, candor and truthfulness, confidentiality, proper attribution, and your supervisory responsibility over others should be carefully managed as they relate to use of GenAI…"
    - "…A good rule of thumb to prevent avoidable perils is to treat GenAI outputs as you would work produced by a new associate: take the time to identify the underlying assumptions, verify their work, and put it through the appropriate quality control processes…

      …By taking these steps you can ensure the accuracy and conformity of all outputs with project requirements and any ethical and legal obligations that may apply, such as those involving confidentiality or proper attribution. Remember, at the end of the day, whether your work product is generated using assistance from a GenAI tool or a human associate, you are ultimately responsible for that work…"
- **ASCE – Artificial Intelligence in Civil Engineering | ASCE – Source**
    - "…engineers must ensure that AI models are created with unbiased data, creating outputs that favor inclusivity, and ensuring that AI is used to aid in work, not fully complete projects for them."
    - Key Excerpts:
        - The key takeaways from the document are:
        - Ethical Challenges: The adoption of AI in civil engineering introduces ethical concerns, such as ensuring unbiased data, inclusivity, and maintaining human autonomy in decision-making.
        - ASCE Code of Ethics: Civil engineers must adhere to the ASCE Code of Ethics, particularly sections 1A, 1B, 1G, and 5F, which emphasize public safety, enhancing humanity's quality of life, inclusivity, and professional development.
        - Unbiased AI Models: Engineers must ensure AI models are trained on diverse and unbiased data to avoid project failures and societal harm. Professional

organizations like ASCE should define standards for unbiased AI models.

- Inclusivity: AI can help bridge educational gaps among engineers from diverse backgrounds, fostering inclusivity in the workplace. Engineers should also ensure AI-generated solutions *consider the social, cultural, and financial needs of communities*.
- AI as a Tool, Not a Replacement: AI should be used as an aid rather than a replacement for human judgment. Engineers must combine AI-generated solutions with human consciousness to ensure ethical and effective decision-making.
- Human Autonomy: Over-reliance on AI could diminish engineers' ability to think independently, which is a fundamental human trait. Engineers must balance AI usage to maintain their autonomy and creativity.
- Future Guidelines: As AI adoption grows, it is crucial to establish guidelines for ethical AI usage and development in civil engineering to ensure safety, inclusivity, and adherence to ethical standards.

- **NCARB – Ethics** **– Source**
  - "NCARB is committed to promoting the highest standards of ethics and integrity within the architecture profession. Ethical behavior is a fundamental requirement of practicing architecture and ensuring each licensed professional upholds their duty to protect the health, safety, and welfare of the public."
  - "To help each of the 55 U.S. architectural licensing boards uphold ethical standards within their individual jurisdictions, NCARB has developed our *Model Rules of Conduct*. The document serves as a national framework that can be adapted by each jurisdiction. In addition, architects who hold the NCARB Certificate are required to certify that they are aware of the *Model Rules of Conduct* when they renew their Certificate each year. Learn more about the development of the *Model Rules of Conduct*."

Ethical Challenges in the AEC Industry when using/integrating AI – Source:

- Disclosing to clients Generative AI was used in any capacity
- Representing AI outputs as fully "human-designed" in marketing/submissions (Remember simply providing the prompt doesn't count)
- Potential bias in AI tools which can compromise safety (e.g., datasets under-representing certain macro and microclimates, building typologies, or not applying building code exceptions)
- Data Privacy and Security
  - "Data sharing security (42%) alongside cost and complexity (33%) were the top integration challenges reported by respondents." – Source
- Professional Integrity and Compliance

FUTURE IMPACT: STAFFING, LICENSURE, AND "AUTHORSHIP" IN DESIGN

- **Staffing**
  - "Employee tenure in architecture and engineering positions has plummeted since 2012 (from 7.1 years to 4.9 years – a decline of more than 30%)" – Source
  - "…we're already seeing clients look out over the next 3-5 years in their strategic plan, and consider supplementing or even replacing staff with AI in production. So AI has the very real potential to help make up for the talent shortage facing AEC firms in the short term…" – Source
  - "56% of respondents say AI helps offset skilled labor shortages." – Source
- **Licensure**: During our research we saw no Generative AI specific training requirements nor any indication that it would be included on the ARE 6.0 administered and released by NCARB.
- **Definition of Authorship**: HUMAN. That is the beginning and the end. Everything stated above continues to point to human authorship and AI being used as a tool.

ISSUE	CURRENT STATUS	PRIMARY RISK TO AEC FIRMS	RECOMMENDED MITIGATION
PROFESSIONAL LIABILITY	If human authorship is proven, then covered under existing copyright laws (in USA) Dependent upon insurer: · Full responsibility on licensed professionals · AI endorsements added for coverage · or AI exclusions added into Professional Limited Liability (PLI) policies	Not meeting the standard of care and thus endangering the health, safety, and welfare of the public Not showing human authorship	Documented human review Disclose AI use to insurers/clients
COPYRIGHT/ INTELLECTUAL PROPERTY	AI outputs not protectable without majority human authorship	Weakened Intellectual Property (IP) in deliverables; potential infringement suits; Little to no copyright protection	Massive human intervention during the editing process Avoid direct submission of raw AI (remember "inspiration only"
ETHICS/ LICENSURE	Human oversight and authorship are mandatory; AI cannot seal and release instruments of service	Probation, suspension, or loss of ability to practice as determined by board	Firm AI policy + consistent training; transparency with clients
FUTURE STAFFING	Possible shift to oversight roles or a position all to itself (Generative AI Specialist)	Skill atrophy in juniors; Reduced entry-level jobs	Balanced training: Use AI as an accelerator, not a crutch

Landmark Case: Mata v. Avianca, Inc. (2023, S.D.N.Y.) – The "AI Hallucination" Precedent **– Source**

Given the prevalent use of Generative AI throughout all industries coupled with the relatable nature of this case across all industries this case is considered as a landmark case by legal professionals.

The Association of Corporate Counsel has a great article along with 3 steps that can be followed to prevent your firm from becoming a landmark case. The steps are geared towards lawyers but general enough to where they can apply to all professionals.

Remember that generative AI creates original content so always fact check and have a human confirm what is claimed is actually true and in existence.

Background: In a personal injury lawsuit filed against airline Avianca, the plaintiff's lawyers used ChatGPT to generate a legal motion, which contained fake legal cases involving fictitious airlines with fabricated quotations and internal citations.

Neither Avianca's lawyers nor the Court could locate the legal cases cited in the legal motion and demanded the plaintiff's lawyers provide copies of the cited legal cases. The plaintiff's lawyers provided copies of most of the legal cases, after ChatGPT reassured them, they existed on reputable legal databases in the law industry.

Landmark Case Outcome (June 2023, Judge P. Kevin Castel):

- Dismissed the personal injury case against Avianca and ordered the plaintiff's attorneys to pay a $5,000 fine.
- The judge held that the plaintiff's lawyers had acted with "subjective bad faith" sufficient for sanctions under Federal Rule of Civil Procedure Rule 11. $5,000 fine (jointly).
- Over a year later, the American Bar Association issued its first formal ethics opinion on the responsibilities of lawyers using generative AI (GAI). The 15-page opinion outlines how the Rules of Professional Conduct apply to the use of GAI in the practice of law

Key Lessons for AEC Firms:

- Over-reliance on unverified AI outputs = breach of duty of competence.
- Parallels in design professions: Submitting AI-drafted code summaries or specifications with hallucinated local, state, and federal code references could lead to licensing board punishment or claims.



Emerging Analogous Cases in Professional Services (2024–2025), see below:

Note: Again, no public AEC-specific liability judgments have been made to date, also note that the option is available to parties to settle quietly or trigger insurance denials pre-claim.

CASE / INCIDENT	YEAR	PROFESSION	AI ERROR	AEC RELEVANCE
Park v. Kim (2d Cir., related to NY state cases) Case in Detail	2024	Law	Attorney cited an opinion that was fake and generated by ChatGPT	Direct parallel: Using GenAI for zoning summaries without verification.
Outcome/Status of Park v. Kim	"...For this GenAI briefing misstep, the Court of Appeals ordered that counsel be referred the Second Circuit's Grievance Panel for investigation (and for possible further referral to the Committee on Admissions and Grievances[22]), that counsel supply a copy of the Court of Appeals' admonishing ruling to her client (translating it into Korean, if necessary for her client to understand it), and then file a docketed certification attesting that she had done so.[23]..." – Food & Drug Law Institute			
Johnson v. Dunn (N.D. Ala. July 23, 2025) Case in Detail	2025	Law	Five hallucinated citations of AI-generated errors in this case	Have AI policies & training in place and always verify the validity of any AI generated anything.
Outcome/Status of Johnson v. Dunn	"...Judge Manasco crafted sanctions designed to deter future misconduct while recognizing the distinction between institutional policies and individual failures. The three sanctioned attorneys received public reprimand, disqualification from the case, and referral to the Alabama State Bar. To ensure the deterrent effect, they must provide copies of the sanctions order to their clients, opposing counsel, every attorney in their firm, and presiding judges in all pending cases where they serve as counsel..." – Source			
Character. AI Wrongful Death Suits (Garcia v. Character Technologies, M.D. Fla. 2025) Case in Detail	2024 – 2025	Tech/Product Liability	"the chatbot, operated by the defendant company, manipulated the teenager through hyper-realistic role-play, including romantic and sexual themes, encouraging self-harm and fostering a dependency that blurred the boundaries between human and machine." – Source	If AI design tools (e.g., ARCHITEChTURES) generate non-compliant life safety plans leading to egress issues, could face a similar lawsuit or claim.
Outcome/Status of Character.AI Wrongful Death Suits	None to date.			

This concludes Part 4 of the course.
Next up is your Part 4 Quiz!

PART 4 – ETHICS, INTELLECTUAL PROPERTY (IP), AND THE FUTURE

KNOWLEDGE CHECK (5 QUESTIONS)

1. **What is NCARB's stance on the use of AI in the architectural profession?**
   A. AI tools should replace professional judgment in technical submissions
   B. AI tools must be evaluated and approved by NCARB before use
   C. Licensed practitioners must remain in responsible control and accountable for all technical submissions
   D. AI tools are prohibited from being used in architectural practice

2. **Why is human oversight critical when using AI in AEC deliverables?**
   A. AI tools are fully reliable and require no verification
   B. Licensing boards require human authorship and professional judgment
   C. AI tools are exempt from liability in case of errors
   D. AI tools automatically meet all regulatory standards

3. **What is a key risk of using AI-generated content in client deliverables?**
   A. AI outputs may contain hallucinations or fabricated information
   B. AI outputs are automatically copyrighted
   C. AI-generated content is always accurate and reliable
   D. AI tools eliminate the need for professional liability insurance

4. **According to the U.S. Copyright Office, what is required for copyright protection of AI-generated works?**
   A. AI-generated works are automatically copyrighted
   B. Human authorship and creative contribution are required
   C. Prompts alone are sufficient for copyright protection
   D. AI-generated works are protected under sui generis rights

5. **What is a recommended best practice for AEC firms using AI in their workflows?**
   A. Submit raw AI outputs directly to clients without review
   B. Avoid disclosing AI use to clients or insurers
   C. Use AI to replace all junior staff positions
   D. Implement "human-in-the-loop" protocols and verify AI outputs

You made it to the finish line!
This concludes the final part, Part 4 of the course.
Continue to the Final Exam.

OUTLOOK AND CONCLUSION

As shown in each part of this course on Integrating Generative AI into the Architectural Workflow, it has been shown that AI is a benefit for any AEC firm. Human involvement is still a must and there must be effort involved no matter what Generative AI type is used.

It has been a joy producing this course for you and us here at MRA Architecture & Design wish you a great day and everlasting success!

INTEGRATING GENERATIVE AI INTO THE ARCHITECTURAL WORKFLOW

KNOWLEDGE CHECK ANSWERS | PARTS 1 – 4

PART 1 – GENERATIVE AI VS. TRADITIONAL AI AND GENERATIVE AI FUNDAMENTALS | KNOWLEDGE CHECK (5 QUESTIONS)

1. **What is the primary difference between Traditional AI and Generative AI?**
   A. Traditional AI creates new content, while Generative AI classifies data; Incorrect.
   B. Traditional AI focuses on creativity, while Generative AI automates tasks; Incorrect.
   C. Traditional AI solves specific problems, while Generative AI creates new content; Correct. Traditional AI is designed to classify, predict, or decide based on structured data, while Generative AI focuses on creating new content, such as text, images, or videos, by learning patterns from large datasets.
   D. Traditional AI uses large datasets, while Generative AI uses structured data; Incorrect.

2. **Which of the following is an example of Generative AI in the AEC industry?**
   A. Identifying whether a material is concrete or steel; Incorrect.
   B. Designing a new urban district with streets, parks, and buildings; Correct. Generative AI is capable of creating new designs, such as an urban district layout, by combining and recombining patterns creatively. The other options are examples of Traditional AI, which focuses on classification and prediction.
   C. Checking if a building complies with local codes; Incorrect.
   D. Predicting the energy consumption of a building; Incorrect.

3. **What is the role of Human Labelers in training Generative AI models?**
   A. Designing the model architecture; Incorrect.
   B. Providing feedback on quality and safety; Correct. Human Labelers play a critical role in training Generative AI by rating responses, labeling examples, correcting mistakes, and providing feedback to improve the model's quality and safety.
   C. Collecting and organizing large datasets; Incorrect.
   D. Running training on large clusters of computers; Incorrect.

4. **What is the purpose of the "fine-tuning" step in Generative AI training?**
   A. To collect and clean large datasets; Incorrect.
   B. To teach the model to predict the next word or pixel; Incorrect.
   C. To refine the model's behavior, tone, and safety; Correct. Fine-tuning involves refining the base model by providing example conversations, correcting mistakes, and guiding its tone, style, and safety.
   D. To evaluate the model using user feedback; Incorrect.

5. **Which of the following is an example of a well-written AI prompt?**
   A. "Make a website look fantastic."; Incorrect.
   B. "Design an intuitive and responsive navigation menu for a mobile travel app."; Correct. A good AI prompt is specific, clear, and provides context. Option B specifies the task (design a navigation menu), the audience (mobile travel app users), and the desired outcome (intuitive and responsive), making it an effective prompt.
   C. "Write something creative about architecture."; Incorrect.
   D. "Create a design that is good."; Incorrect.

PART 2 – GENERATIVE AI PROMPTING STRATEGIES, TYPES, AND EXERCISES | KNOWLEDGE CHECK (5 QUESTIONS)

6. **What is the key characteristic of a Zero-Shot prompt?**
   A. It provides examples for the AI to follow; Incorrect.
   B. It defines the AI's role and constraints; Incorrect.
   C. It is clear, concise, and does not include examples; Correct. A Zero-Shot prompt is direct and does not provide any examples for the AI to follow. It relies solely on the clarity of the input to generate the desired output.
   D. It asks the AI to solve a problem in multiple steps; Incorrect.

7. **Which prompting strategy involves assigning a persona or role to the AI?**
   A. Contextual prompting; Incorrect.
   B. Role prompting; Correct. Role prompting assigns a specific persona, context, or point of view to the AI, such as asking it to act like a travel agent or a historical figure, to tailor its responses accordingly.
   C. Chain of Thought prompting; Incorrect.
   D. Step-Back prompting; Incorrect.

8. **What is the purpose of the "Chain of Thought" (CoT) prompting strategy?**
   A. To provide multiple examples for the AI to follow; Incorrect.
   B. To break down complex problems into smaller, logical steps; Correct. Chain of Thought prompting improves AI reasoning by asking it to solve problems step-by-step, which is particularly useful for tasks like mathematics, coding, or decision making.
   C. To define the AI's role and constraints; Incorrect.
   D. To generate multiple outputs and select the best one; Incorrect.

9. **Which of the following is an example of a Text-to-Image AI model?**
   A. GPT-4; Incorrect.
   B. BERT; Incorrect.
   C. Stable Diffusion; Correct. Stable Diffusion is a text-to-image AI model that generates images based on textual descriptions.
   D. OpenAI Codex; Incorrect.

10. What is the primary function of Latent-Space Modeling in Generative AI?

A. To generate text based on learned language patterns; Incorrect.

B. To create images from textual descriptions; Incorrect.

C. To encode and manipulate data in a lower-dimensional abstract space; Correct. Latent-Space Modeling compresses high-dimensional data into a simpler, abstract representation (latent space) and generates new outputs by exploring and manipulating this space.

D. To provide step-by-step reasoning for complex problems; Incorrect.

PART 3 – GENERATIVE AI FOR AEC: AI FOR AUTOMATION AND BUSINESS EFFICIENCY | KNOWLEDGE CHECK (5 QUESTIONS)

11. Which of the following is a use case for Text-to-Image (TTI) AI for architects?

A. Generating inspection scenario examples for staff education; Incorrect.

B. Visualizing structural systems from text prompts; Incorrect.

C. Conceptual façade design visualization; Correct. Text-to-Image AI is particularly useful for architects in visualizing conceptual designs, such as façades, interiors, and sustainable features, based on textual descriptions. The other options are more relevant to inspectors, engineers, or contractors

D. Creating visuals for client progress updates; Incorrect.

12. What is a key benefit of Latent-Space Modeling for architects?

A. Generating diagrams for client presentations; Incorrect.

B. Exploring façade style blending and massing variations; Correct. Latent-Space Modeling allows architects to explore creative design options, such as blending façade styles or generating massing variations, by sampling from patterns in the latent space.

C. Simulating on-site safety hazards; Incorrect.

D. Creating visuals for marketing proposals; Incorrect.

13. Which of the following is an example of a Large Language Model (LLM) use case for architects?

A. Drafting RFI responses and tracking logs; Incorrect.

B. Generating building programs from client conversations; Correct. LLMs are highly effective for architects in tasks like converting client conversations into building programs and project approaches, helping streamline the early design process.

C. Visualizing common safety hazards from descriptions; Incorrect.

D. Creating before-and-after remediation images; Incorrect.

14. What is a common workflow for automating specification writing with Generative AI?

A. Uploading zoning ordinances and requesting summaries; Incorrect.

B. Generating visuals for fire safety and egress paths; Incorrect.

C. Creating marketing visuals for proposals and portfolios; Incorrect.

D. Combining office master specifications with project-specific requirements; Correct. Generative AI can streamline specification writing by merging office master specifications with project-specific requirements, producing a clean first draft that is later reviewed by a human professional.

15. How can AI assist in automating code and zoning summaries?

A. By extracting zoning envelopes and egress requirements from ordinances; Correct. AI can automate code and zoning summaries by extracting zoning envelopes, egress requirements, and other relevant details from ordinances or building codes, providing quick insights for feasibility studies and early design phases.

B. By generating diagrams for presentations or client approvals; Incorrect.

C. By creating visuals for urban planning projects; Incorrect.

D. By simulating potential code violations for training purposes; Incorrect.

PART 4 – ETHICS, INTELLECTUAL PROPERTY (IP), AND THE FUTURE | KNOWLEDGE CHECK (5 QUESTIONS)

16. What is NCARB's stance on the use of AI in the architectural profession?

A. AI tools should replace professional judgment in technical submissions; Incorrect.

B. AI tools must be evaluated and approved by NCARB before use; Incorrect.

C. Licensed practitioners must remain in responsible control and accountable for all technical submissions; Correct. NCARB emphasizes that AI is a tool, not a replacement for professional judgment. Architects must remain in responsible control and ensure all technical submissions meet the standard of care.

D. AI tools are prohibited from being used in architectural practice; Incorrect.

17. Why is human oversight critical when using AI in AEC deliverables?

A. AI tools are fully reliable and require no verification; Incorrect.

B. Licensing boards require human authorship and professional judgment; Correct. Licensing boards, such as NCARB and NSPE, mandate that professionals exercise oversight and verify AI outputs to ensure compliance with ethical and legal standards, as AI cannot replace human judgment.

C. AI tools are exempt from liability in case of errors; Incorrect.

D. AI tools automatically meet all regulatory standards; Incorrect.

18. What is a key risk of using AI-generated content in client deliverables?

A. AI outputs may contain hallucinations or fabricated information; Correct. AI-generated content can include hallucinations (fabricated or inaccurate information), which, if unverified, can lead to errors, liability claims, or breaches of the standard of care.

B. AI outputs are automatically copyrighted; Incorrect.

C. AI-generated content is always accurate and reliable; Incorrect.

D. AI tools eliminate the need for professional liability insurance; Incorrect.

19. According to the U.S. Copyright Office, what is required for copyright protection of AI-generated works?

A. AI-generated works are automatically copyrighted; Incorrect.

B. Human authorship and creative contribution are required; Correct. The U.S. Copyright Office states that copyright protection requires significant human authorship. AI-generated elements alone are not eligible for copyright protection unless creatively modified or arranged by a human.

C. Prompts alone are sufficient for copyright protection; Incorrect.

D. AI-generated works are protected under sui generis rights; Incorrect.

20. What is a recommended best practice for AEC firms using AI in their workflows?

A. Submit raw AI outputs directly to clients without review; Incorrect.

B. Avoid disclosing AI use to clients or insurers; Incorrect.

C. Use AI to replace all junior staff positions; Incorrect.

D. Implement "human-in-the-loop" protocols and verify AI outputs; Correct. AEC firms should adopt "human-in-the-loop" protocols to ensure AI outputs are verified by licensed professionals, maintaining compliance with ethical and legal standards while reducing risks.