Physics, Construction, Experience: An Architectural Environment for Informal Science Education

by Benjamin Black

Submitted to the Department of Architecture in partial fulfillment of the requirements for the degree, Master of Architecture, at the Massachusetts Institute of Technology, February, 1996.

Signature of the Author
Benjamin Black
January 19, 1996

Certified by
Fernando Domeyko, Senior Lecturer
Thesis Supervisor

Accepted by
Ann Pendleton-Jullian, Chair
Departmental Committee on Graduate Students

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Abstract

While contemporary informal science education facilities (to include science centers, natural history museums, aquariums and zoos) have dramatically evolved from the 17th century room of curiosity cabinets to the modern-day container of interactive exhibits, very little has been done to incorporate architectural experience into a pedagogical mission. This thesis investigates how architectural experiences can be constructed as integral components of an informal science learning environment. While the building serves as a container of the facility, it also serves as a device to consciously establish territories of direct interaction with the behavior of natural phenomena. Grounded primarily on scientific concepts related to physics, the mission of this particular science center relies substantially on the experimentation, participation, and critical inquiry of citizens to construct their own knowledge. It is located in Seattle on a prominent urban site associated with existing and developing cultural infrastructure.

Thesis Supervisor: Fernando Domeyko
Title: Senior Lecturer
Acknowledgments

This thesis is dedicated to Dana, because she has taught me to love life more than architecture.

I would like to thank my Family for encouraging me to enroll at MIT, Fernando Domeyko for encouraging me to stay, and Jack de Valpine for encouraging me to finish.

Thanks also to my thesis critics, Tim Elliason and Prof. Akos Moravanszky, for helping me see this project in more than one way.

Also Todd, Scott, and Randy, for helping me keep my eyes on the West while I've been away.

And a special thanks goes to the people at KrekowJennings for showing me the beauty of building.
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Many people today would conclude that current public science education is at a point of crisis. Several studies have shown that scientific principals and the profession of science are misunderstood by many people. Misunderstandings are created in part by popular media and advertising, as well as formal education and contemporary museums of science. This is a crisis, not only because many important decisions that guide our future depend on an understanding of science and technology, but also because learning science is a powerful and legitimate way of building knowledge. New theories in education purport that people most readily construct knowledge of science through physical, social and intellectual accessibility, direct experiential relationship with natural phenomena, and association of new experiences with previously constructed schemas. This thesis examines how a built architectural environment can encourage and activate science learning in an informal public setting.

Science
Contrary to popular belief, science is not simply a collection of “facts” and “laws.” Science is also a process of organizing and structuring the universe by observing and interpreting the behavior of natural phenomena.

Example:
Observation 1: Sun rises in the east and sets in the west. Interpretation 1: Earth is fixed, Sun revolves around Earth.
O2: Night stars seem to move.
I2: Stars move around fixed earth.
O3: More careful observation reveals that stars rotate around one point.
I3: Earth still fixed, stars rotate around fixed point in the night sky; or stars are fixed and Earth spins under fixed point.

O4: Over a period of one year, the “fixed” point seems to gradually move up and down in the sky with respect to the horizon.

I4: “Fixed” point is not fixed at all.

O5: Change in altitude of sun throughout the year corresponds with movement of “fixed” point.

I5: Sun and stars behavior are related; perhaps it is Earth that is doing the moving and not the sun and stars.

In this example, continued observations and interpretations with increasing depth could possibly lead to the knowledge that the earth does in fact revolve around the sun and that the sun is simply one of many stars. The process is ongoing and open to change in order to facilitate continuous and healthy development of knowledge. The process is additionally enhanced when other individuals make different observations and interpretations of the same phenomena. Through cooperation and communication, individuals work together in order to develop a shared understanding of the phenomena. Naturally, the widest and deepest construction of knowledge can occur when many diverse people are able to contribute creatively and cooperatively to the process of science.

**Constructing Knowledge of Science**

This thesis takes a constructivist perspective as a model for learning. Constructivism is a theory of learning that relies on an individual’s direct experience and interaction with the universe in order to build knowledge. It states that through various experiences and interactions, individuals piece together schemas that help organize and structure their understanding of the universe. A schema enables an individual to predict and expect certain results when faced with similar experiences and interactions from their past. An individual’s collection of schemas constitutes their body of knowledge. Periodically, a schema can be disrupted when expectations from experiences and interactions are not met. In such cases, an individual will examine the disruption and modify their schema to incorporate the new experience. Knowledge is constructed through these disruptions and modifications of schemas.

This way of building knowledge is articulated by the previous example about observations and interpretations in a scientific process. The observer is building and modifying a schema
about the relationship between Earth, the Sun, and the stars. Successive observations allow the individual to continue modifying the schema until it is no longer disrupted by unexpected results. Knowledge evolves and is constructed through the various interpretations and modifications of the schema.

Learning by construction is an extremely powerful way of building knowledge, particularly in science. It does not rely on authoritative individuals or texts to give answers about the world. Instead, it encourages individuals to seek their own answers through their own experiences. Learning by construction fosters critical thinking, inventiveness and creativity. People tend to have greater confidence about their knowledge when they have developed a schema from their direct interactions. Most importantly, the process of constructing knowledge is interchangeable with the process of science.

A Place For Learning Science
This investigation is concerned with integrating the construction of scientific knowledge with built form. Throughout the investigation, I have identified three principal factors to consider in order to make the integration.

1) The building is an observational device to experience and interpret natural phenomena. For the sake of this study, I have limited the observational opportunities to relate to the materials: earth, air, water, and light and their associated phenomena to include gravity, pressure, tension, compression, waves, sound transmission, temperature, color, etc.

2) The building itself is made in a way that encourages participants to build and modify various schemas about its structure and organization. In this way, the architectural environment performs as an entity to be explored.

3) The facility aims to be physically, socially, and intellectually accessible to the community it serves. It should be identifiable as a public facility, welcoming and approachable to all citizens, and have a personality that causes people to want to explore.
1. Arial photo. Site includes entire block marked by arrow. Central business district is to the SW (skyscrapers). Pike Place Market is in lower left, and the Elliot Bay waterfront is in the foreground.
The site chosen for this investigation is an urban block in the city of Seattle, Washington. The block, bounded by Second and Third Avenues and University and Union Streets, is situated in the city between the downtown office core to the south and the retail district to the north. Within comfortable walking distance is the legendary Pike Place Public Market, The Seattle Aquarium, The Seattle Public Library, several hotels, and The Washington State Convention Center. The Seattle Art Museum, designed by Venturi/Scott-Brown, is directly across Second Avenue from the site. Also located adjacent to the site is one of five direct access-points to the Metro Bus Tunnel that operates below Third Avenue. The recently completed “Harbor Steps,” a pedestrian-only access way, continues University Street down the steep hill to the waterfront. The site has a significant possibility of intensifying the connection between the city and the water’s edge as well as the retail and business districts. Recent developments in the vicinity have included high-end urban housing projects that build the steep edge between the waterfront and the city in an attempt to re-vitalize the urban neighborhood. It is anticipated that this trend is favorable and will continue. The site is currently vacant.

In developing this site for a public building, I believe that the following five points should be considered.

1) Create outdoor public area.
2) Maintain a direct link to the Bus Tunnel.
3) Open building toward sun and water.
4) Continue street level commercial activity.
5) Build service access from the alley way.
2. Model showing streets and city blocks built into the hillside.
3. Section through University street.
4. Diagram of access paths around the site. Dark areas represent increased pedestrian activity.

5. Photo toward site taken from Harbor Steps. Seattle Art Museum is seen on the left.
6. Diagram showing foot traffic into and out of the bus tunnel.
7. Photo of site taken from corner of 2nd and University, toward the bus tunnel access.
8. Diagram of the site orientation toward the sun and water.
9. Photo from site in late winter toward light and water.
10. View of site from corner of 3rd and University. Bay is visible in lower left corner.
General Organization

The Facility is organized around a central outdoor area that serves both as a public urban gathering space, and as a connecting device between the bus tunnel and the city. Three buildings contain the exhibit halls, staff offices, and service areas for the facility in addition to providing some closure for the central outdoor space.

Site territory directly accessible from the street is either commercial space, central outdoor area, or the facility's main lobby area on the corner of Third Avenue and University Street. Entrances to the site are made either from the bus tunnel, the corner of Second and University, onto the terraces from University Street, or directly into the main entrance from Third Avenue. Commercial spaces occur on the street level north of the bus tunnel on both Third Avenue and Second Avenue.
Service areas and a parking garage are accessed from the alley off Union Street on the north side.

The three buildings rise independently from the ground, but are connected through the air with enclosed bridges and at the ground level with outdoor terraces. Each building is made with a slightly different building system relating to the different phenomenological characteristics of earth, air, water and light. A system of water cycles through the site from the roof of the northeast corner, to a horizontal plane, down the terraces of the north, into a vertical plane on the southwest end, and finally into a street level pool. Between and inside the buildings, observations and interpretations are encouraged to occur through the experience of architecture.
15. The Grand Canyon.
16. Articulated ground of the facility.
17. El Capitan, Yosemite National Park.
18. Building structure reaching to meet the sky.
20. Diagram of water system from roof, to terraces, to water wall.
21. Trees and light, Richardson Redwood Grove, California.
22. Diagram of stick building structures.
23. Early plan, ground level.
24. Early plan, upper level.
25. Early section showing lecture hall underground.
26. Early section showing connection to bus tunnel.
27. Plan showing path of views depicted by figures 28 - 40 (following pages).
28, 29. View from corner of
2nd and University. Seattle Art
Museum is immediately to the
left in the photo.
30. Corner of open area.
31. Toward platform that connects terraces.
32. Water pool.
33. View to north terraces and bridge.
34. Foucault Pendulum linking sky and Earth through the force of gravity.
35. Under raised platform.
36. View through opening in platform toward bridge.
37. Through platform to pendulum and sky beyond.
38, 39, 40. Approach to bus tunnel.
41. Plan showing path of views depicted in figures 42 - 50 (following pages).
42. View out of the bus tunnel.
43. Early oil sketch showing compressive force/weight above and light beyond.
44. 45. Lateral compression and sky revealed.
46. Toward platform and light.
47. 48. 49. 50. Under the platform and into the open.
51. Section through long direction of facility, parallel to 2nd and 3rd Avenues. Terraces negotiate the site topography, cover service area on the north (right in figure), and orient the facility toward the sun and water.
52. View from terrace near side entry off University Street.

Views From Terraces
53. View from ground level up to south terraces, adjacent to University Street.
54. View from above side entry. Taken from horizontal plane just above the center in figure 53.
55. 56. Approach from south terraces to main entry.
57. View out toward open space from main lobby. Seattle Art Museum beyond.
58. Under bridge.
59. Toward north terraces (right side in figure 51).
60. From upper floor inside building overlooking terraces and water system.
Side Entrance
61. Photo of site from alley off University Street. Location of proposed side entrance to site.
62. 63. Views from side entrance.
64. 65. Views from the platform between terraces.
66. 67. 68. Leaning wall and its base connection.
69. Section showing relationships between bus tunnel and site, platform and canyon, bridge and buildings, dark and light.
70. View into canyon.
Canyon
71. Photo of site taken directly above existing bus tunnel access.
72. View from same location in model.
73. Axonometric diagram showing geometry of canyon.
74. Section through canyon facing the direction of the water.
75. Axonometric diagram of compressed bridge in canyon.
76. Early study of compressive force of leaning wall.
77. Inside lower bridge looking up toward sky.
78. View into canyon from 3rd Avenue.
79. 80. Pendulum from lower bridge in canyon.
81 Early explorations of bridge.
82. Connection.
83. Inside bridge looking down. Wood in compression, steel in tension. Wooden deck hangs from structure.
84. Section through bridge.
85. Tension pieces and connectors.
86. Connection.
87. Compression members.
88. Connection.
89. 90. 91. Views from inside the bridge.
92. Early sketch of stick building.
93. View from top immediately after crossing bridge.
94. Worm's eye view of roof structure.
95. Early sketches of roof structure.
96. View from upper level of building.
97. Longitudinal section showing sticks and patches of light and dark.
98. View from middle looking up toward roof.
99. Early oil sketch of vertical elements revealing the sky.
100. Middle floor.
101. Ground floor.
102. Glass/water wall.
103. Early sketch of glass wall to hold water as an observational tool to demonstrate pressure, light, color, and volumetric transformation from horizontal plane of water above north terraces.

104. (opposite page) Light enters building through colored cast glass drums.
Like concrete form work, planes of glass hold water. Metal spokes, tension rings and tension rods prevent glass planes from "blowing out." Cast glass segments form drums under compression from the water surrounding them and form a seal against the glass planes. The assembly is stabilized by external cables in tension between the ground and a supporting structure.

(Opposite page.) Detail of rod/ring/drum structure.
107. View from ground floor toward wall.
108. (Opposite page) Axonometric drawing of glass and metal elements.
This project was launched from an ongoing conversation with Dana Riley that began in the summer of 1994 while traveling to the West. For years she had been investigating the field of informal science education, and I had become interested. Eventually, it had occurred to me that if informal science education were to take place in a built environment, then architectural experience must have a significant impact. Thus, the thesis was born.

Although the facility presented in this book is far from complete, I hope that it can be useful as a base for continuing research into the aspects of built science learning environments. To make the project more complete, I think it would be worthwhile to look more carefully at the connections between the various building strategies as well as making the interiors of the three different buildings more articulate.

Even if the facility presented here was more complete, I believe that it would need to be built in order to test its effectiveness on creating an inspiring learning environment. For now we can only imagine, but it is my hope that architects will eventually be able to lead communication that can result in more considerate environments for public education. With inventiveness and concentration, I believe it is possible for architects to incorporate a way of building that encourages people to explore and to learn. When created thoughtfully, architecture can be much more than a container with a few representative icons. It can be a place that is memorable and inspiring through inhabitation and experience.
Figure Credits

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12. Robert Cameron, Above Seattle, p. 9
15. Ansel Adams, Our National Parks, p. 93
17. Ansel Adams, Our National Parks, p. 14
19. Ansel Adams, Our National Parks, p. 23
21. Ansel Adams, The Print, p. 113
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