ABSTRACT

Title of Document: REDEFINING PROCESS: AN EXPLORATION OF DIGITAL DESIGN, FABRICATION, AND ASSEMBLY THROUGH THE CONSTRUCTION OF A BICYCLE STATION

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Digital technology has allowed new territories, unthinkable decades ago to be explored. It has not only allowed architects to dream up and generate complex fluid designs through the use of 3D modeling software, but it has also allowed architects to give physical form to the digital realm through new techniques in digital fabrication. This thesis investigates a process of digital design, fabrication, and assembly through the exploration of carbon fiber as a building material and how it can be used to give physical form to the digital realm.

This process is tested through the design of a bicycle station that is to be located in two different urban conditions in Washington, D.C. The first bicycle station is inserted into an existing building located on Farragut Square. This insertion will explore prefabricated carbon fiber surface and how it can be inserted into existing architecture. The second bicycle station is located at Union Station. Union Station is.

REDEFINING PROCESS: AN EXPLORATION OF DIGITAL DESIGN, FABRICATION, AND ASSEMBLY THROUGH THE CONSTRUCTION OF A BICYCLE STATION

By

Michael Allen Fischer

Thesis submitted to the Faculty of the Graduate School of the
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Advisory Committee:
Associate Professor Madlen Simon, Chair
Assistant Professor Deborah Oakley
Professor Karl DuPuy

Dedication

I would like to dedicate this thesis to my family for all their love, support, encouragement, and most of all patience.

Acknowledgements

I would like to thank my committee, Madlen Simon, Deborah Oakley, and Karl DuPuy for all their guidance and support throughout the year. I would like to thank all of the faculty that have guided me throughout my time here at the University, and the following students and staff who helped me make the presentation come together, Mercedes Afshar, Josh Cole, Aaron Kreinbrook, Mozhedeh Matin, Lin Mao, Claudia Santos, Sean Weston, and Nastaran Zandian.

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Introduction

Digital technology has manufactured a new and uncanny environment for architectural design to occur. The digital realm has allowed new territories, unthinkable decades ago to be explored. Specifically, it has allowed for the control and visualization of complex forms during the design process. Despite this control, the digital representation often relies on the effect of suggested forms and few statements concerning materials, production, and assembly are given. When the advanced geometries are realized, they are done so by falling back on traditional building methods creating an end product that often does not resemble the intended result.

This thesis suggests a process in which design, materialization, production, and assembly relate to each other in a logical sense. Specific application of materials and production techniques can bring design and assembly more in line withe each other. Designers need to be more aware of the possibilities of the various materials and apply them based on its characteristic qualities.

Traditionally, digital media has been used as a representational tool for design. Architecture needs to utilize digital media not as a representational tool for visualization but rather as a generative tool for the analysis and derivation of form. Parametric design allows for digital technologies to generate design. This generative design process allows there to be a direct connection between design and assembly by allowing material, production, and assembly constraints to be applied to the design. By varying the constraints, this process not only defines the building's form but also allow for the possibility of several solutions of the building to exist (Figure 1).

Often times the result of the parametric design process is a design consisting of fluid curves.

These complex amorphous shapes consist of thin surfaces where few places of the surface are identical. The current process of creating these forms is through triangulation, which creates the form by connecting a number of flat panels at different angles. Although there is a proportional relationship between the entire form and the small parts that make up the form, the desired affect is not always attainable (Figure 2). To truly realize the form in an accurate way, every part of the form should be fluid (Figure 3).

Digital fabrication equipment allows for the digital information of the fluid form created by digital media to be translated into physical form. This equipment allows for the manipulation and use of materials that would not have been possible years ago. Steel is now bent, plasma cut, and welded to specifications described by the data sent from the digital model. Concrete curvilinear forms are now created by digitally fabricated form work. Buildings have the possibility to take new forms with traditional materials that were unable to be realized decades ago. This technology also allows the application of new materials to create these forms. Through the use of digital fabrication, carbon fiber, a material used extensively by the aeronautical and automotive industries, can be applied to architecture. This material allows the possibility of skin and structure to become one by allowing the design to take a structural form. This allows for new possibilities in the design of the built environment.

Because they are designed for the automotive and aeronautical industries, current CAD/CAM systems have been developed because of serial production. These industry's desire for serial production in large numbers contrasts with the differentiation of form of the fluid computer model. This means that prefabrication of fluid design can only be cost-effective when founded on a flexible serial method.

When carbon fiber is used for the production of double curved shell segments, there is a need for it to be created using a reusable form work. Reusable form work can make a

Figure 1. Systems of the Human Body
The human body is made of a series of systems that function together. Each system has a direct relationship to the other systems in the body. They are interdependent of each other and have evolved based to some part because of this relationship. The result is the body's form. Much like the body, architecture can be through of as a series of systems. Site, program, structure, and materiality all affect how the building is designed, produced, and assembled. [Versioning 30]

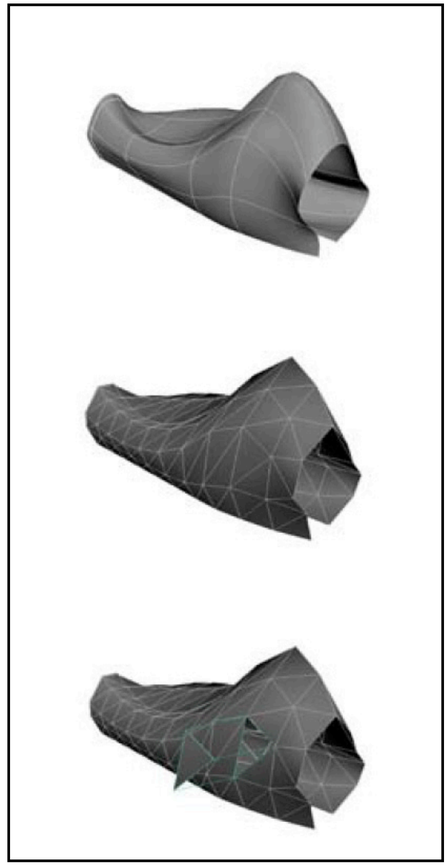


Figure 2. Fluid Form Translated into Flat Panels Top shows original complex fluid form. Middle shows the triangulation of the fluid form. Bottom shows how the form is made up of a series of flat panels. Through this transformation the form is loses the desired affect but remains more cost-effective.

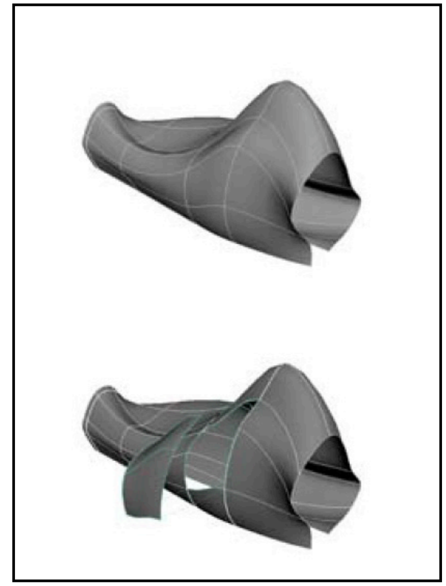


Figure 3. Fluid Form Translated into Fluid Panels Top shows original complex fluid form. Bottom shows how the form is made up of a series of fluid panels. Through this transformation the form retains the desired affect but is less cost-effective. The use of a reusable form work can make the complex geometries of the panels more affordable and sustainable.

small series of unique shapes affordable by allowing the form work to be reused for all the shapes. The starting point of the reusable mold system is the definition of the double curve, which is defined in the computer as a set of points. The surface is created from these points which is directly translated to the reusable form work. The result is a series of unique panels that fit together to make a larger surface. This allows the intended fluid surface to be accurately physically represented.

This investigation is tested on two bicycle stations located in the Washington, D.C. area. A bicycle station is a facility that provides secure storage for bicycles as well as showers, lockers, coffee shop, and bicycle shop for the riders in an effort to promote an alternative form of transportation, which will alleviate parking issues and encourage personal and public health.

The first exploration tests how carbon fiber can be used at a human scale by designing a bicycle station that is inserted into an existing building. Taking its form from programmatic and infrastructural conditions, this exploration looks at how prefabricated carbon fiber components can be inserted into an existing building while also taking a structural form.

The second examines how surface can be designed by using environmental factors such as sun light and rain water, as well as factors such as site and program to determine the surface's form. It tests how the surface can be fabricated and assembled using carbon fiber.

This thesis is an exploration of complex form and examines how program, site, and material can affect the design of the form. It looks at how new techniques can be used to fabricate it, how new fabrication techniques allow for new materials and how all of these is interrelated.

Process of Digital Design, Fabrication, and Assembly

Architects have historically looked beyond their discipline for innovative technologies that can advance the field of architecture. During the Renaissance, architects relied heavily on the expertise of ship builders. Palladio's Basilica at Piazza dei Signori in Vicenza (1617) relied extensively on the building expertise of ship builders to construct the roof, which was basically an inverted ship hull[1] (Figure 4).

Figure 4. Andrea Palladio, Basilica at Piazza dei Signori, Vicenza, Italy
The roof of this building relied heavily on the building expertise of ship builders. The roof structure is essentially an inverted ship hull.

Much like in the Renaissance, architects today can look towards other disciplines to inform architecture. Architects are now beginning to look at the way the aerospace and automobile industries have used digital technology to coordinate and connect design and construction and are now starting to apply it to architecture.

Much of the developments in architecture in the last decade occurred due to the advances made by architect Frank Gehry. It was his design of the Vitra Design Museum in Weil-am-Rhein that led him to look outside of architecture and toward the aerospace industry for ways to design and build his architecture. In this project he attempted to create a roof system that changed in all three directions (Figure 5). The difficulty he ran into was that he was unsuccessful in describing this three dimensional element on two dimensional construction documents. The result was a design that he was dissatisfied with, which led to a desire to change the way he described his building for construction. This project led Gehry to explore the possibilities of using 3D software in his later works. By using software such as Catia, which is aeronautical engineering software, he was able to full describe the complex geometries of his later buildings and digital fabricate the pieces. This implementation of digital technology in his firm served as a catalyst for developing architecture specific 3D software.[2]

Figure 5. Frank Gehry, Vitra Design Museum, Basel, Switzerland
Frank Gehry's design was unsuccessfully built due to the inability to describe complex curves using traditional architectural representation. This building led him to explore other industries tools for describing such conditions to their fabricators.
[Photo by Claudia Santos]

Digital Generators of Form

Traditionally, digital media has been used as representational tool for a design. In recent years digital media has evolved from a representational tool for visualization to a generative tool for the analysis and derivation of form. Greg Lynn has been one of the leading advocates for defining how architects can use this advanced technology for design and how to integrate it into construction. One example of this is in his Port Authority Bus Terminal where he uses a parametric design process[3] (Figure 6).

[redacted]

Figure 6. Greg Lynn's Port Authority Bus Terminal
The design of the protective roof and lighting scheme uses parametric design by subjecting the basic structure of the object to a series of forces created by the forces associated with the flow of pedestrians, cars, and buses across the site. [Greg Lynn Form]

Parametric design is a design process in which the designer can create an infinite number of design possibilities through the assignment of a series of variables with specific values. In parametric design, it is the parameter that is defined, not the shape. By assigning different values to the parameter, different solutions can be created. This is usually done through the creation of scripts. Scripting refers to the a process in which the designer writes a series of equations with a programming language which describes numerical constraints and conditions for the design. Using parametric modeling and scripting in the design process is particularly useful for modeling buildings with complex geometric forms. The International Terminal at Waterloo Station in London is a clear demonstration of developmental benefits of using a parametric approach to design. Because the roof responds to complex geometric site issues, its form is a 400m long glass-clad train shed, with a tapering span that shrinks from 50m to 35m, made of 36 dimensionally different but identically configured three-pin bow string arches. Instead of modeling each arch separately, a scripted parametric model was created based on series of variables that related size of span to its curvature. By assigning different values to the span parameter, the 36 different arches were computed and inserted into the overall model[4] (Figure 7).

Figure 7. Nicholas Grimshaw and Partners
International Terminal, Waterloo Station 1993, London, UK.
The parametrically designed three-pin bowstring arches are dimensionally different but identical due to applying a scaling factor to the truss geometry. This design process allows each truss to be quickly designed based on a predetermined set of parameters.[5] [Nicholas Grimshaw and Partners]

Related to parametric design, performative architecture is another design process that is emerging out of the digital technology. This design process utilizes the digital technologies of qualitative and quantitative performance based simulation as the guiding principle and places this new approach above form making. In performance-based design, an emphasis can be placed on a number of factors including financial, social, and cultural to technical issues. Norman Foster's City Hall, in London, was designed using performative design process where much of its form is generated based on a desire for it to be energy efficient. This type of design process made available by digital technology is redefining building design, process, and practice[6] (Figure 8).

Figure 8. Foster and Partners, City Hall, London, UK.
Energy analysis helped determine the form of the building. From the beginning, the building was intended to be energy efficient, so the form was a resultant of this analysis which was performed through 3D modeling software. [Foster and Partners]

Digital Production

Digital Production refers to the processes and methods of transition between the digital and physical realm. These processes include reverse engineering, CNC Fabrication, Rapid Protyping, and Formative Fabrication.

Many designers have a desire to start to design with hand drawings or a physical model. With this technology the model or paper is scanned and a subsequent digital representation is created. Frank Gerhy used this technology extensively for his design for the Guggenheim Museum in Bilbao, Spain. In this project he used a three dimensional scanner to give digital form to his physical models. This process referred to as "reverse engineering," uses a laser scanner to digitally capture the geometry of the physical model. The physical model is scanned, resulting in a file consisting of point clouds. The point clouds are then edited and aligned creating the digital model (Figure 9).

Figure 9. The process of translation from the physical to the digital realm in Frank Gehry's Office
Object is scanned using a 3D laser scanner. The object's geometry is translated in digitized points known as a point cloud. The digital surface is reconstructed based on these points giveing a digital representation of the physical object. [Gehry Partners]

CNC Subtractive Fabrication refers to a fabrication method, which creates exact physical objects of a digital model by removing material from a starting block, rod or sheet through computer control movement. There are a number of CNC fabrication machines that can be used to create the complex geometry of the digital realm depending on its materiality. The types of equipment are generally broken into the 2D and 3D fabrication equipment. The most common of these CNC fabrication machines are routers, lathes, milling, drills, saws, laser cutters, plasma cutters, and water jets.

Rapid prototyping or 3D printing refers to a fabrication method that creates an exact physical object of a digital model by taking the virtual designs, transforming them into thin, virtual, horizontal cross-sections and then creating each cross-section in physical space by stacking one after the next until the model is finished.

CNC Formative Fabrication refers to a fabrication method, which creates exact physical objects of a digital model by bending a rod or sheet of material through computer control movement. This is performed by using material that has bending properties such as metal and bending them with a machine that uses a series of rollers to manipulate the geometry of the object. Much of Frank Gehry's buildings use formative fabrication techniques for the creation of the thin curving panels that he is known for. On the design for the Experience Music Project in Seattle, Washington, he used this process for fabricating the steel and aluminum skin of the façade.[7]

[redacted]

Figure 10. Digital Fabrication Equipment
Top Typical subtractive CNC equipment. It can move in multiple directions to remove excess material and reveal the form. **Middle** Typical formative fabrication equipment using rollers and press brake to bend form into shape. **Bottom** Typical rapid prototyping equipment which adds material layer by layer to build object. [Shodek, 251]

Digital Assembly

Digital technology not only has allowed for a change in the way buildings are designed and fabricated, but also in how they are assembled. It has allowed changes in the planning for assembly, as well as the techniques for assembly.

BMW Dynaform, a project by BMW for the 2001 Frankfurt Motor Show shows the way digital technology has the potential of changing the planning of the assembly of buildings. With the aid of digital technology, the project for a 13 day exhibition was designed in 167 days and constructed in 84 days. The success of the project is in large part due to the extensive use of building information modeling or BIM.

BIM is a database of information about geometry, spatial relationships, geography, and quantities and properties of building components. BIM allows for multiple disciplines to work simultaneously on the same project allowing for direct communication through the use of digital technology. When one database is edited, all other databases are coordinated and edited. Not only does it allow each discipline to use the model simultaneously, it also allows each user to view the model differently. It allows structural engineers to work with data presented graphically in familiar framing and bracing diagrams, quite different from the interface architects use. BIM also serves as a scheduling device for a project. The model stores information on all the components of the building with respects to time and location so that each piece can be coordinated with the project as a whole.

The designers of Dynaform used car manufacturing programs such as CATIA and Mechanical Desktop to develop the its design and to preview how complex forms can be projected and produced. This technology allowed for digital mock-ups, which in turn allowed production, transportation, and assembly to be simulated. The information from the digital mock-up could then be quickly evaluated and a series of versions of the design were created and tested. This was very important for this project because of the limited amount of time allowed for assembly and disassembly of the building[8] (Figure11).

Figure 11. BMW Dynform Fabrication and Assembly Process.
Top The trusses are fabricated from sheets of steel using CNC plasmacutter. **Middle** The pieces are CNC welded together to make the truss. **Bottom** The wall assembly is evaluated off-site. [Bernhard Franken and ABB Architekten]

Digital technology also allows for changes in how buildings are assembled. This is shown in Shop Architect's Camera Obscura project in New York. This is Shop's first fully digitally designed and fabricated projects. Through the use of digital technology, this 350-square-foot building was built as a kit of parts, which included instructions much like that of a model airplane kit.

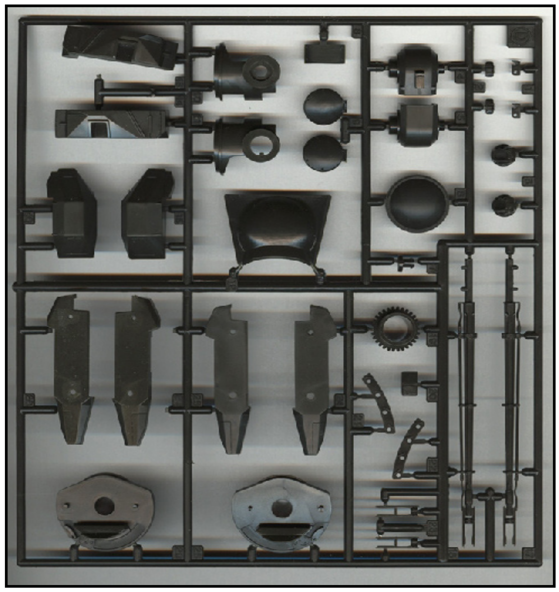


Figure 12. Airplane Kit of Parts.
Children's model airplanes are designed as a kit of parts. Each piece has an etched number that corresponds both to assembly order and instructions.

The assembly process started by precisely locating the building's foundation using GPS technology. The form work for the building's curvilinear foundation was made from CNC routed wood. The wood was etched with instructions for ease of fabrication and assembly.

The aluminum and steel components that attached to the foundation were laser cut using the digital information extracted from the computer model. Like the wooden foundation components, they were also etched with assembly instructions. After off-site fabrication, these components were sent to the building site and attached to the concrete foundation.[9]

[redacted]

Figure 13. Shop Architects, Camera Obscura, New York, New York.
This irregularly shaped project used digital technology for design, fabrication, and assembly. [Shop Architects]

[redacted]

Figure 14. Camera Obscura Assembly Instructions
The assembly instructions describe how the project is to be assembled using the prefabricated components. [Shop Architects]

Figure 15. Camera Obscura Assembly
The irregularly shaped concrete foundation was made by digitally fabricated wooden form work .
[Shop Architects]

Figure 16. Camera Obscura Assembly
The prefabricated components are placed on the concrete foundation.
[Shop Architects]

Creating Complexity from Modularity

Complex geometric form does not necessarily mean that the components making the form have to be unique. Digital technology can be used to take identical components and make complex forms.

This is shown by Shop Architect's Dunescape at P.S.1. Contemporary Art Center. The project for an "Urban Beach" installation in the courtyard of P.S.1. Contemporary Art Center, was designed not by stylistic and formal considerations, but rather driven by program and technique. Designed to be deployed and configured as a landscape, the project is made of a triangulated frame, which shifts based on programmatic requirements. The frame itself is made by only two elements (2x2 cedar sticks and 3 inch wood screws), which were designed to be fast tracked. The result is a complex irregular surface made of identical components.[10]

Figure 17. Shop Architects, Dunescape at PS1, New York, New York.
This design for an "Urban Beach" created a complex geometric surface using repeated elements. The varying surface was made by changing the angle of connection of the 2x2 cedar sticks.
[Shop Architects]

Carbon Fiber

Digital technology allows for the use of new materials that could not have been used with traditional design and fabrication techniques. One material that is now being used by the automobile and aeronautical industries because of the advances in digital design and fabrication technology is carbon fiber.

Carbon Fiber Reinforced Plastic is a composite material made of continuously woven carbon fiber and resin. The existence of carbon fiber came into being in 1879 when Thomas Edison took out a patent for the manufacture of carbon filaments suitable for use in electric lamps. It was not until the early 1960's when successful commercial production was started. It was originally used for the aerospace industry because of its strength to weight ratio. In recent decades, carbon fiber reinforced plastic has found wide application in commercial and civilian aircraft, recreational, industrial, and transportation markets. Nearly all of Boeing's new aircraft are constructed with carbon fiber. The material is incredibly plastic and allows for a monocoque or structural skin to be used for the hull design. Unibody design is a related construction technique for automobiles in which the body is integrated into a single unit with the chassis rather than having a separate body-on-frame. On the new Mercedes McClaren SLR, the entire uniboby is made from carbon fiber.[11]

Figure 18. Mercedes SLR
Mercedes design for the SLR uses carbon fiber for the uni-body and exterior panels giving the car strength while saving on the weight The exterior skin, traditionally made from aluminium, is made from carbon fiber because of carbon fiber's ability to take any form. [Daimler Chrysler]

Composite materials are engineered from two or more materials, each with significantly different physical and chemical properties, and which remain separate on a macroscopic level within the finished structure. The two materials are referred to as the matrix and the reinforcing material. The matrix material surrounds the reinforcement material while the reinforcing material provides special mechanical and physical properties that enhance the matrix properties. In Carbon Fiber Reinforced Plastics (CFRP) the carbon fiber is the reinforcing material. Carbon fiber is a fibrous carbon material having a micro graphite crystal structure made by fibrillation of Acrylic resin or oil/coal pitch. The epoxy resin is the matrix.

3D modeling software and 3D CNC routers allow for virtually any shape or form to be designed and produced because of the ease of producing the molds and carbon fiber's plastic properties. Complex shapes that were incredibly expensive to fabricate can now be easily produced with this new technology. This also allows for studies in new systems. Much like the aerospace industry, architects can explore how carbon fiber can be used to allow the skin and the structure of the building to be one entity.

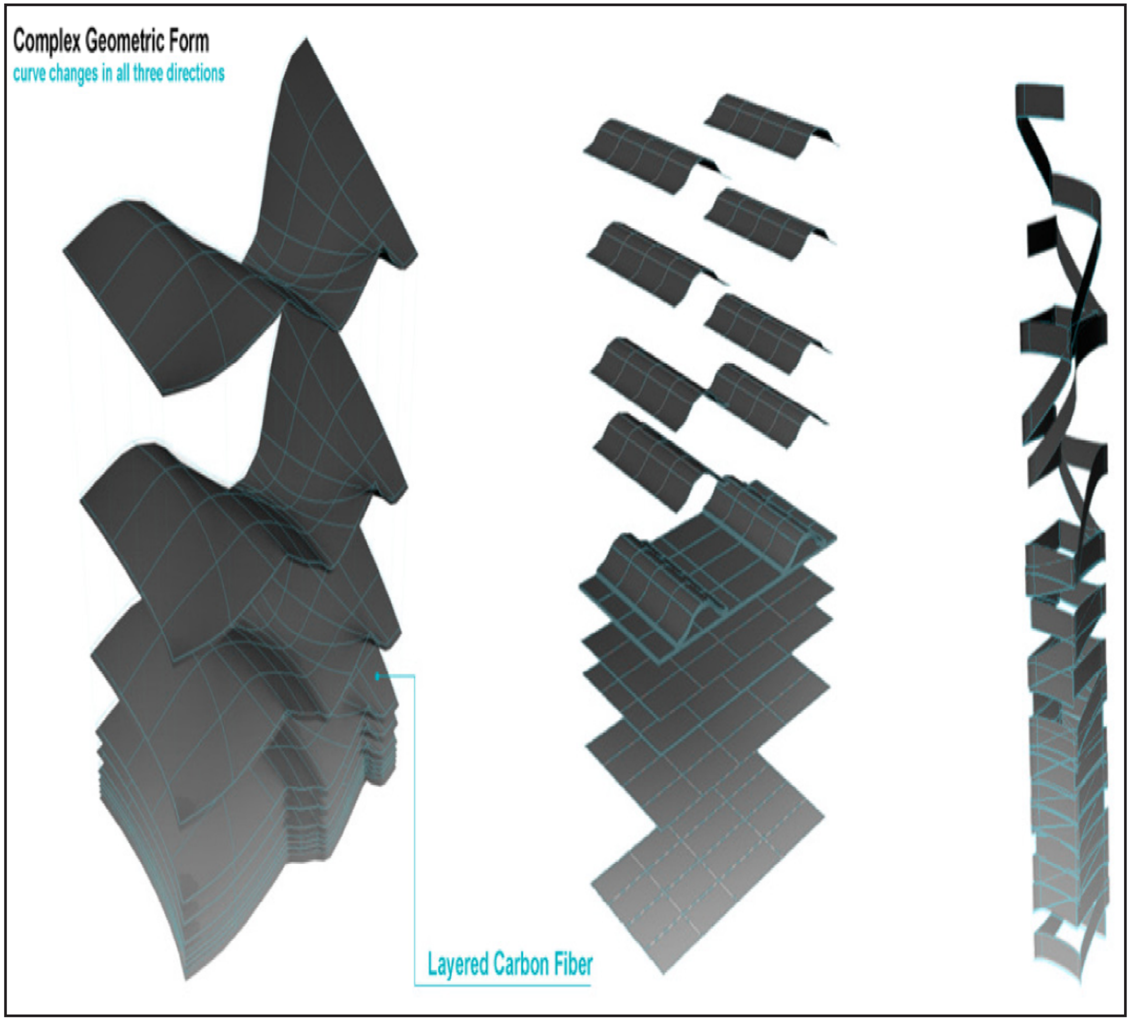


Figure 19. Carbon Fiber Forms - Carbon fiber reinforced plastics can be made into virtually any form. Complex geometries can be layered up to create irregular skin. Structural geometry can also be added to a skin to create a structural skin. Pipes and columns can be created through the wrapping of carbon fiber around a form.

Figure 20. Carbon Fiber Examples - Carbon fiber can be configured to virtually any shape. It is so versatile it can be used to shape a something as complicated as a bicycle helmet or as simple as a bicycle frame.

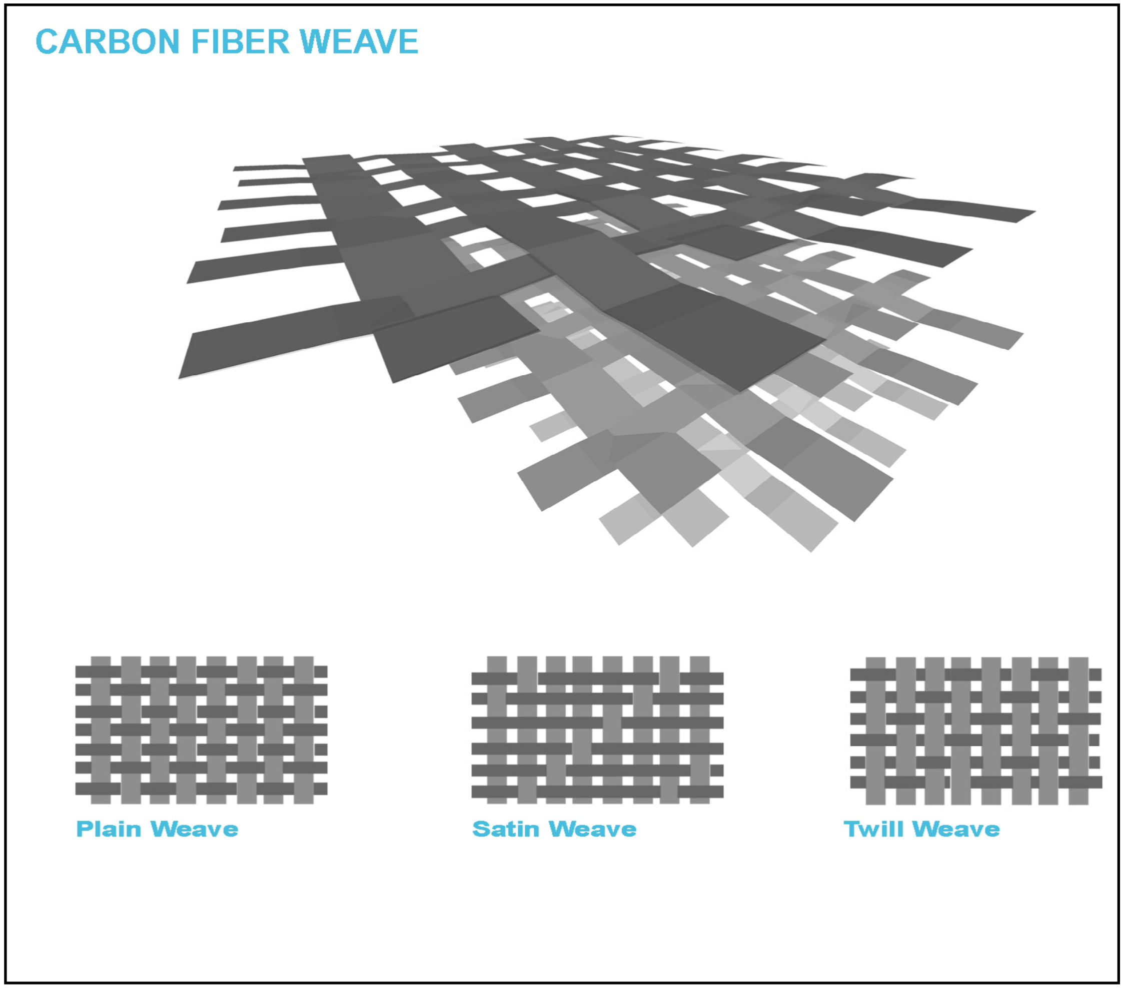


Figure 21. Matrix and Reinforcement
Carbon fiber reinforced plastics are made from a matrix and reinforcement. The matrix is the resin where as the reinforcement is the carbon fiber weave. The composite is made by impregnating the carbon fiber with the resin and then applying it on a form. Layers of the impregnated carbon fiber are laid over one another and built up to the appropriate thickness. The resin is then cured giving the composite structural properties of both.[11]

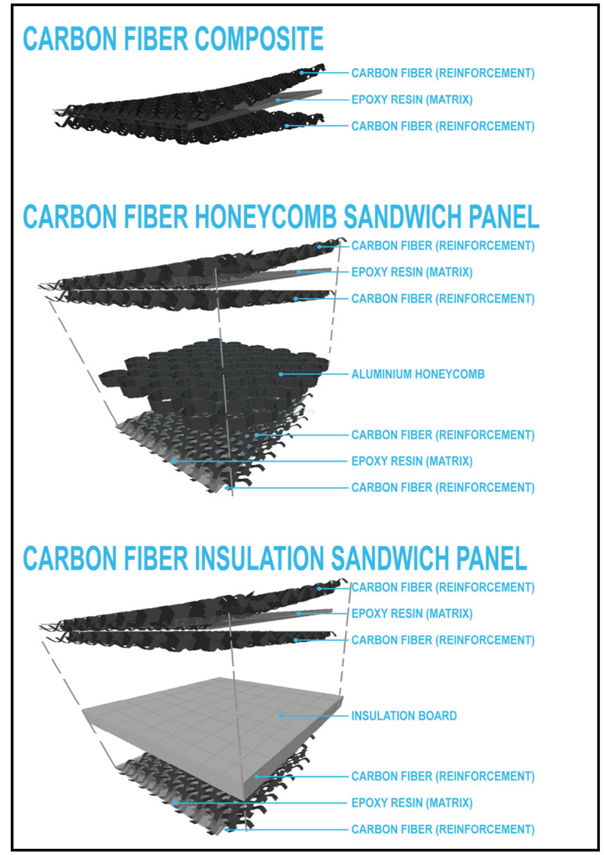


Figure 22. Carbon Fiber Composites
Carbon fiber can be added to various materials based on the needs of the design. **Top** Carbon fiber composite made of only carbon fiber and resin. **Middle** Carbon fiber combined with aluminum honeycomb structure to make a sandwich panel. The combination of the two give the surface more strength. **Bottom** Carbon fiber combined with insulation board give the surface both strength and insulation value.[12]

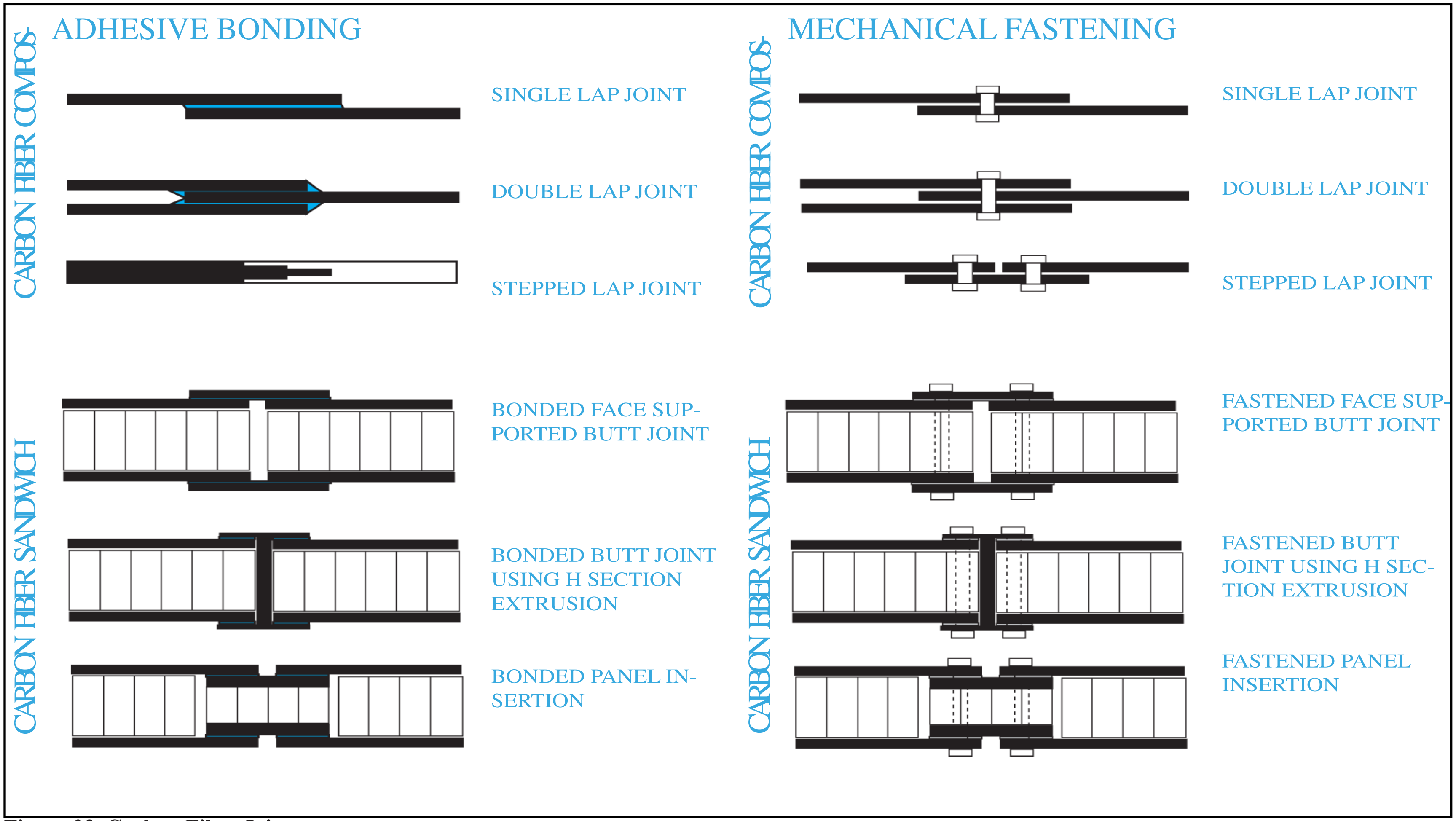


Figure 23. Carbon Fiber Joints

Carbon fiber composites and sandwich panels can joined using adhesive bonding or mechanical fastening Adhesive bonding provides an appearance of a continuous surface and allows for a weather tight membrane but the bonding must occur in a controlled environment[13] to ensure a quality bond. Mechanical fastening can be performed on-site but does not provide an appearance of a continuous surface and additional measures must be taken to ensure a weather tight surface.[14]

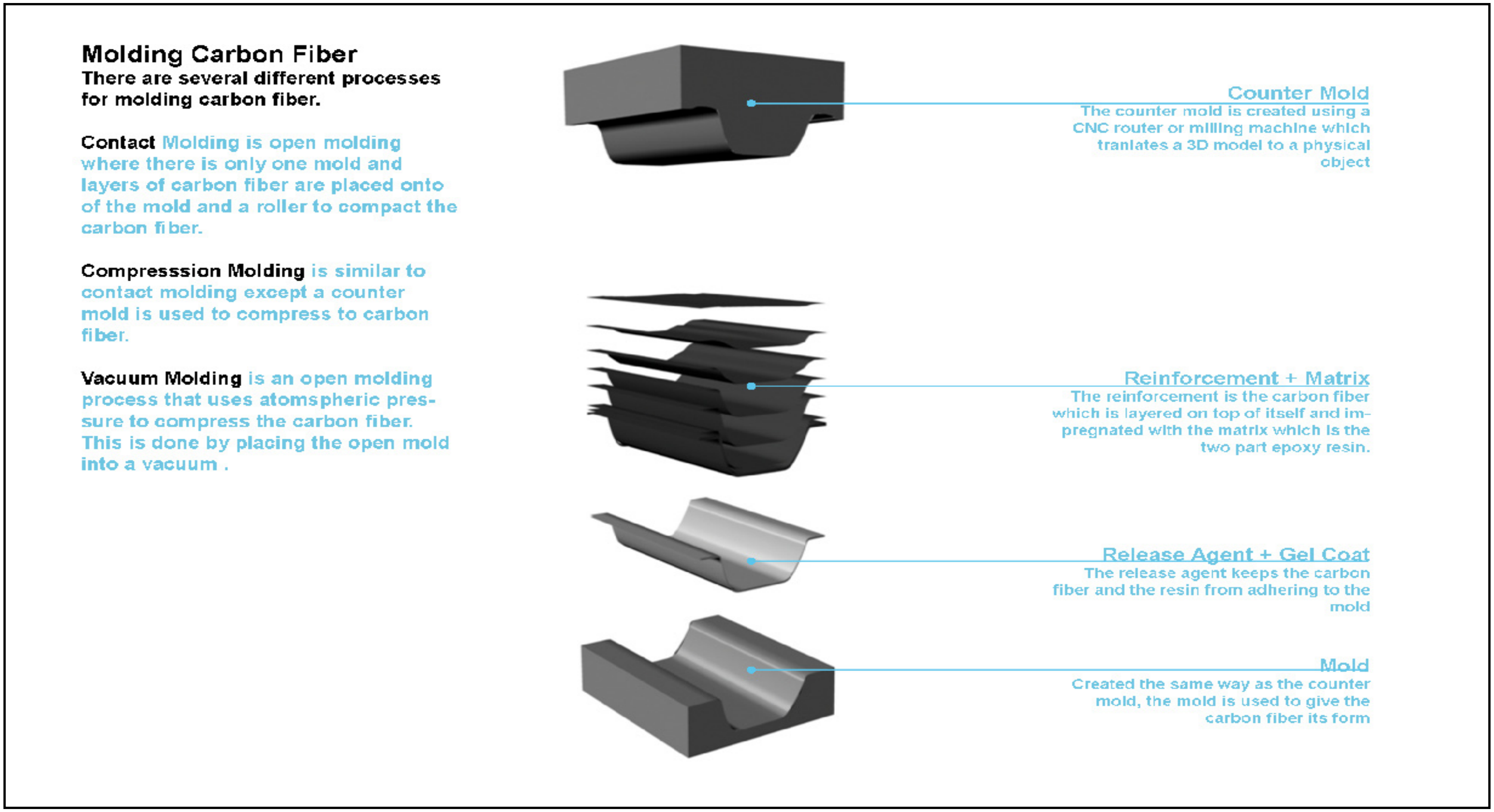


Figure 24. Molding Carbon Fiber

Carbon fiber reinforced plastics are made through the process of molding. A digitally fabricated mold is made with a 3D CNC router. A release agent is applied to the mold so the carbon fiber will not adhere to the mold. The carbon fiber is impregnated with an epoxy resin and laid in the mold and allowed to cure. After the carbon fiber cures it is removed and the mold can be reused to make the same form. This technique is best used for serial production of a form as it is expensive to make one off form work.[15]

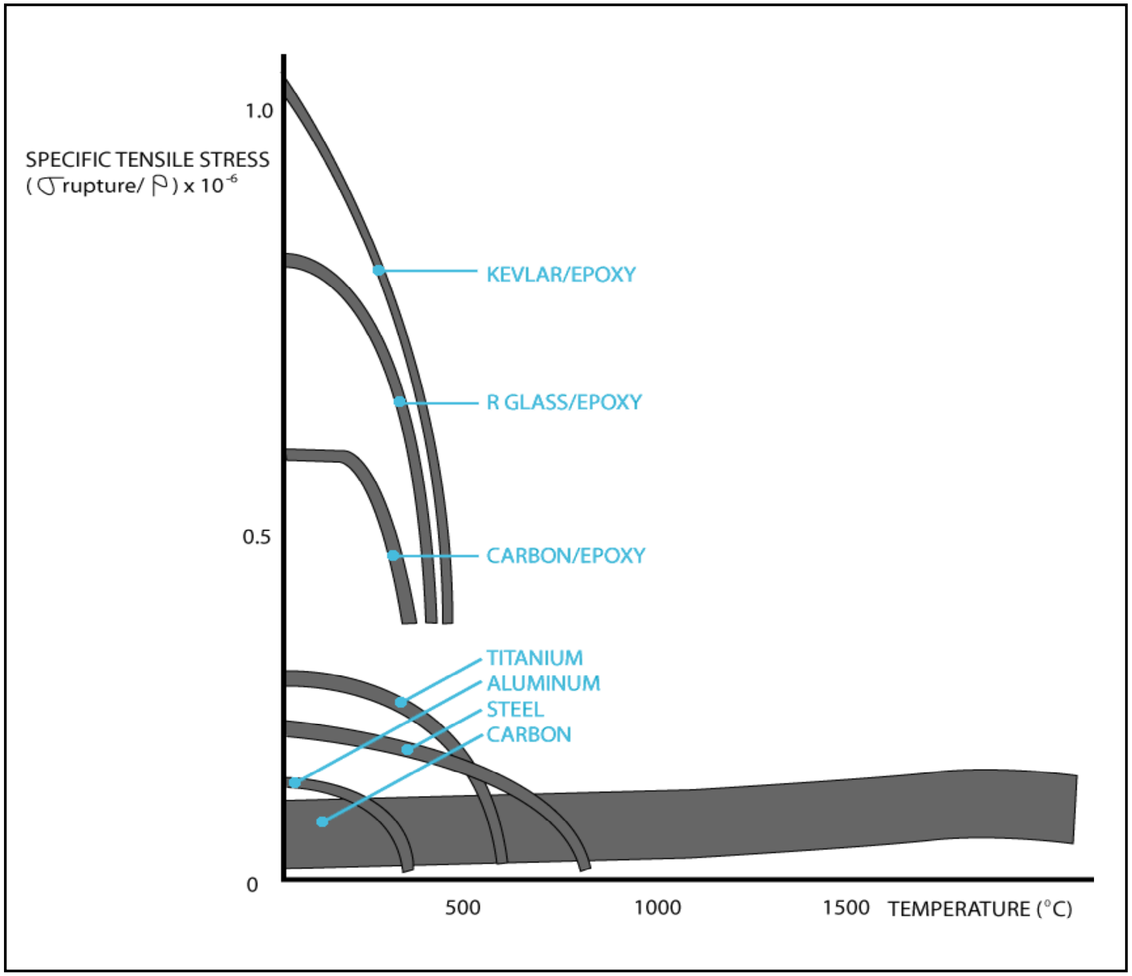


Figure 25. Structural Properties of Carbon Fiber Compared to Other Materials
Carbon Fiber Reinforced Plastics (CFRP) is superior to steel or glass fiber reinforced plastics (GFRP) in its specific tensile strength and specific elastic modulus. CFRP is light in weight and strong in its mechanical performances. For its strength it is 5 times lighter than steel. It also has higher resistance to fatigue than steel and aluminum but lower thermal conductivity and expansion.[16]

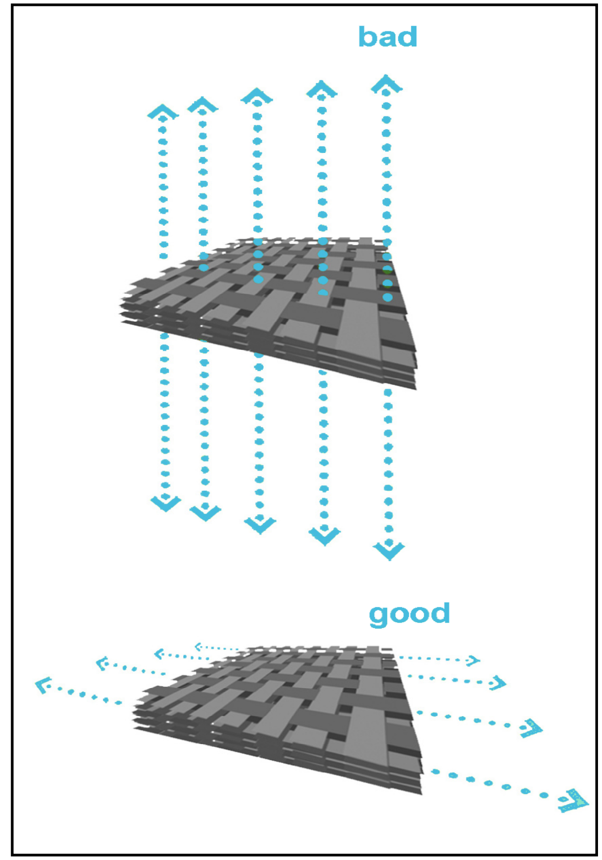


Figure 26. Carbon Fiber in Tension
Carbon fiber reinforced plastics are incredibly strong for tension but only if the carbon fiber is correctly oriented to take the load. In the first example the load is pulling the fabric in a way that the resin is under load. This will cause the composite to fail through delamination. The second example shows the proper use of carbon fiber. The load is pulling the fabric in a way that the fabric is resisting the force.

Exploring Carbon Fiber for the Built Environment

As architects bring technology from other design disciplines into architecture, the technology will need to be modified to fit the requirements of architecture. Based on the automotive industry, which uses serial production in large numbers, the current process for making carbon fiber involves molding the material over CNC routed wood or foam form work. Unlike automobiles, which are reproduced in the thousands, a building is only produced once. Because buildings are one off, the current process of creating unique form work is not ideal. If architecture is to take advantage of carbon fiber as a building material, the process in which the carbon fiber is formed needs to be modified. Architecture needs a form work that can be reconfigured and reused so that it is more sustainable and cost efficient. The scale of the components required by each industry also differs. While the components required by the automotive industry are small, the building industry requires components that are large. The hood of a car is easily fabricated into one component, where as the skin of the building because of its size, would need to be fabricated from hundreds of components. Architecture needs to develop new techniques for breaking down large complex geometries into smaller components and ways to join these components together.

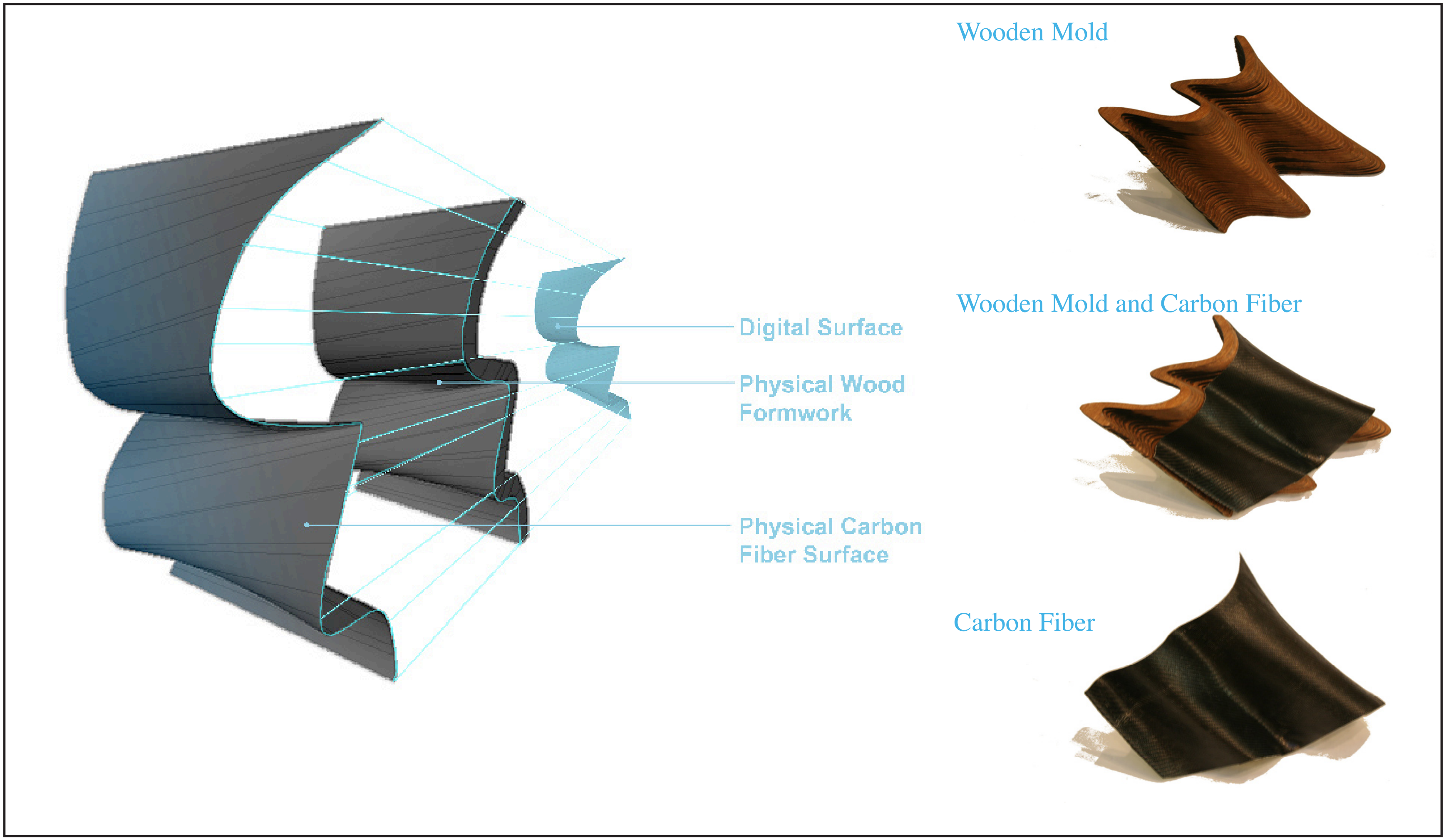


Figure 27. From Digital to Physical - Testing the Carbon Fiber Form Work

Through the use of digital technology, a digital form is made physical out of carbon fiber. The form is created in Autodesk's Maya software. A digital mold is created from the surface and is fabricated out of wood using a CNC lasercutter. The carbon fiber and epoxy resin is laid on the mold and allowed to cure. The carbon fiber is removed and the physical version of the digital object is formed. With a serial production of this surface, the process is optimal, but with only one

A Modular System to Produce the Unique

When applying carbon fiber to architecture, the current form work system used to form carbon fiber is too small and inefficient for architecture. A new system needs to be created that allows large scale complex surfaces to be broken down and formed in efficient and sustainable ways.

One way these complex geometries can be broken down is by applying a regular grid to the large form. By applying a grid, the surface is broken down into smaller similar sized components that can be easily fabricated on a reusable form work system.

The inspiration for the design of a reconfigurable reusable form work comes from the childhood toy Pinpressions by PinArt. The toy has 4500 individually controllable pins that slide to match the contour of the form behind it.

Figure 28. Pinpressions and Wire Mesh
The formwork takes its insperation the children's toy Pinpressions. The toy allows virtually any surface to be recreated by using 4500 controllable pins. In order to refine the surface further, a wire mesh is also used. [Pinart]

Likewise, the reusable form work, which relates directly to the dimensions of the individual components created by the applied grid, consists of individual equally spaced controllable rods that create the physical surface for the carbon fiber to lay. Inspired by the way surfaces are manipulated in the digital realm, the control rods of the form work relate directly to the control points of the digital surface. Modifying the physical surface of the form work simply involves moving a control rod in the Z direction. A wire mesh is used for the carbon fiber to lie on. It is created by cables that connect the control rods in both the X and Y directions. This system allows virtually any digital form to be physically recreated on the reusable form work.

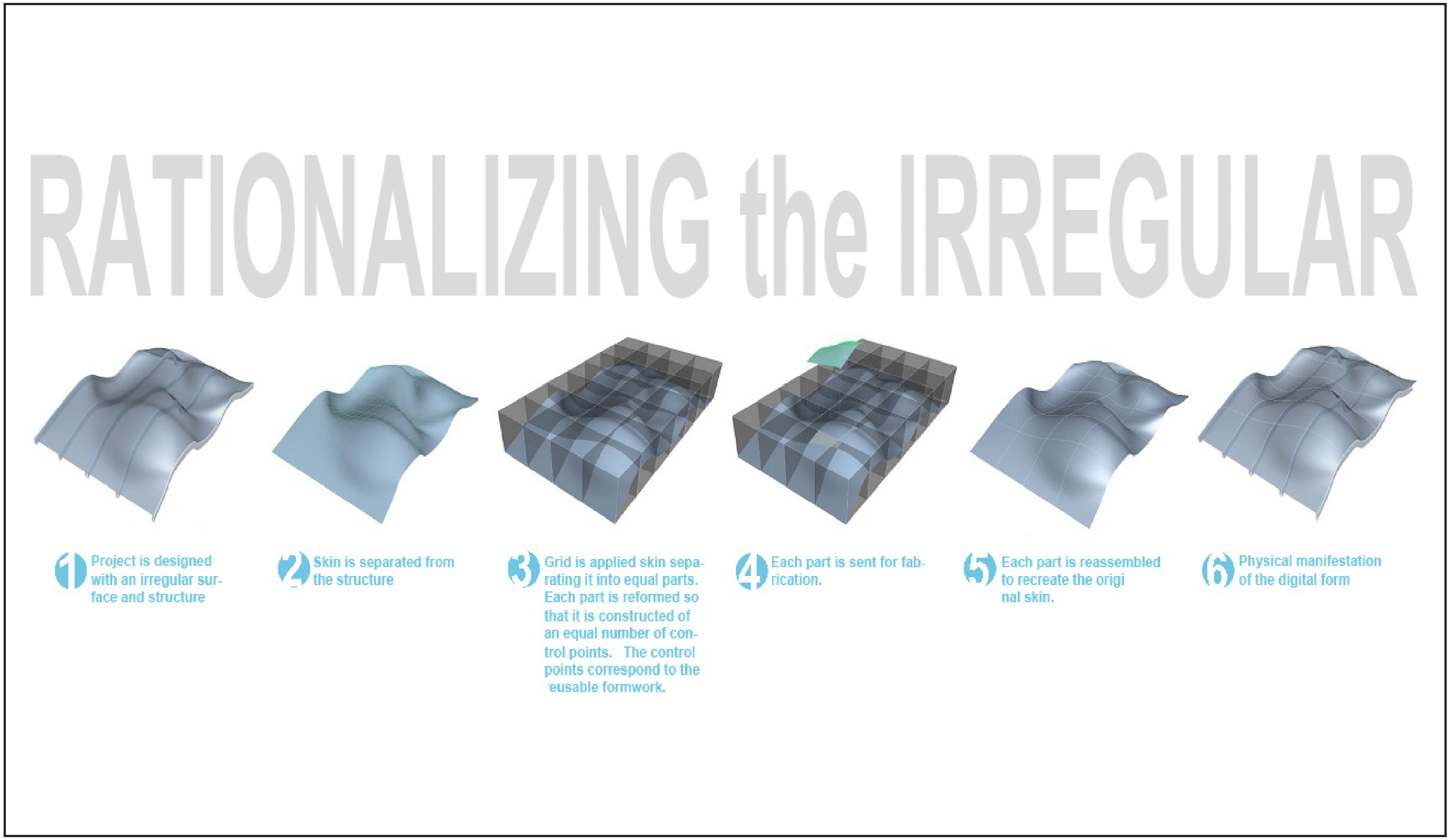


Figure 29. From Digital to Physical - Breaking Down the Complex Digital Surface

Large complex geometries can be broken down by applying a grid to the surface and breaking the surface into smaller components based on that grid. The smaller digital components would be made up of a set number of control points equally spaced in the X and Y directions. The control points would relate directly to the form work that would be used for fabrication.

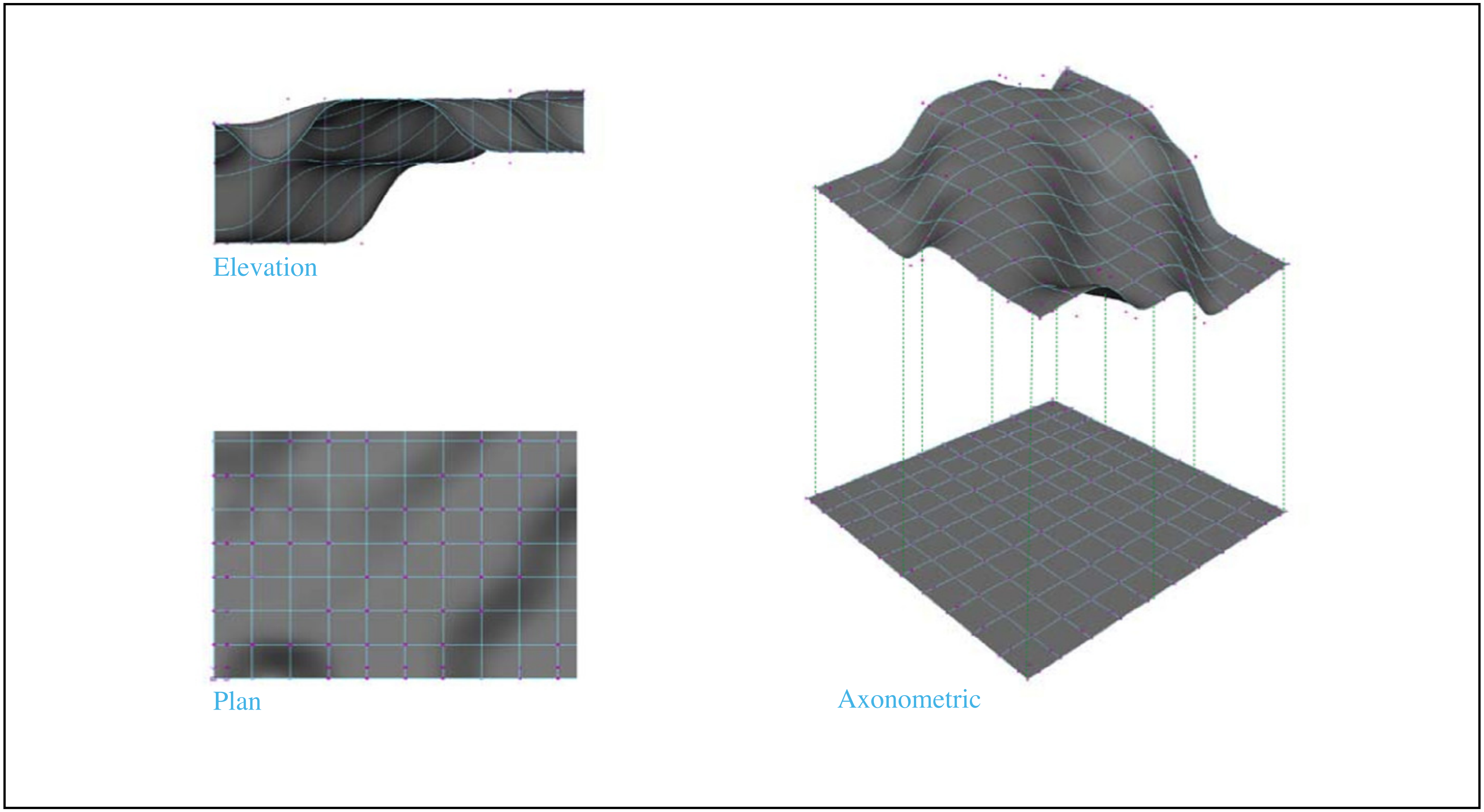


Figure 30. From Digital to Physical - The Digital Surface
After the surface is broken down into smaller components it is rebuilt to fit a standard grid. In plan the surface appears regular because the control points are equally spaced in the x and y directions. These control points will correspond to the reusable form work's control rods. The elevation shows how the control points create the surface by its location in the z direction. This change in height corresponds to the control rod's change in height. Therefore there is a direct relationship to how the surface is described in both the digital and physical realms.

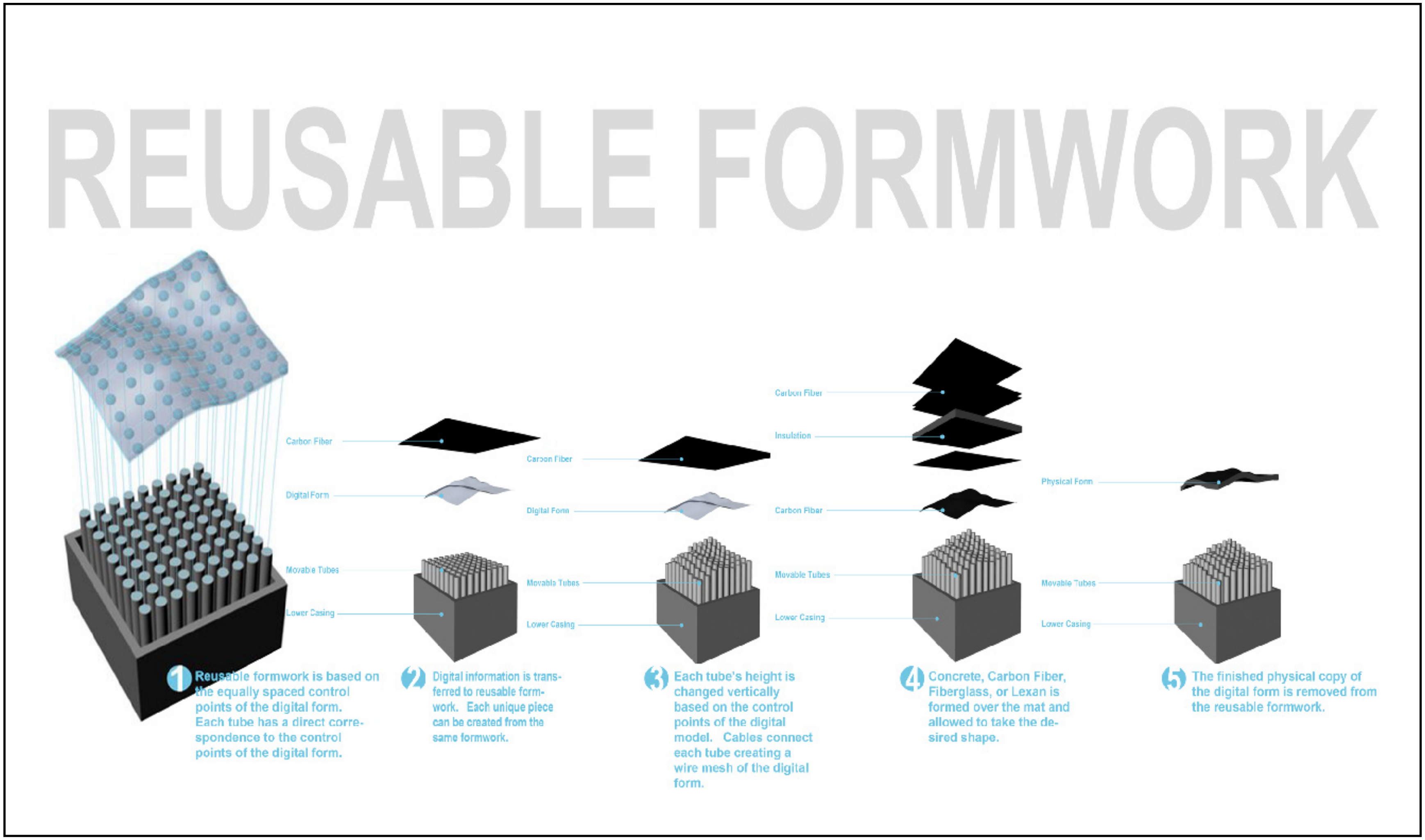


Figure 31. From Digital to Physical -The Fabrication Process
After the individual surface is rebuilt to fit the reusable form work system, the fabrication process can begin. By using a system consisting of controllable rods, the form work can make virtually any surface desired by simply adjusting the height of each control rod. After the surface is molded, the rods can be reconfigured to create another unique surface.

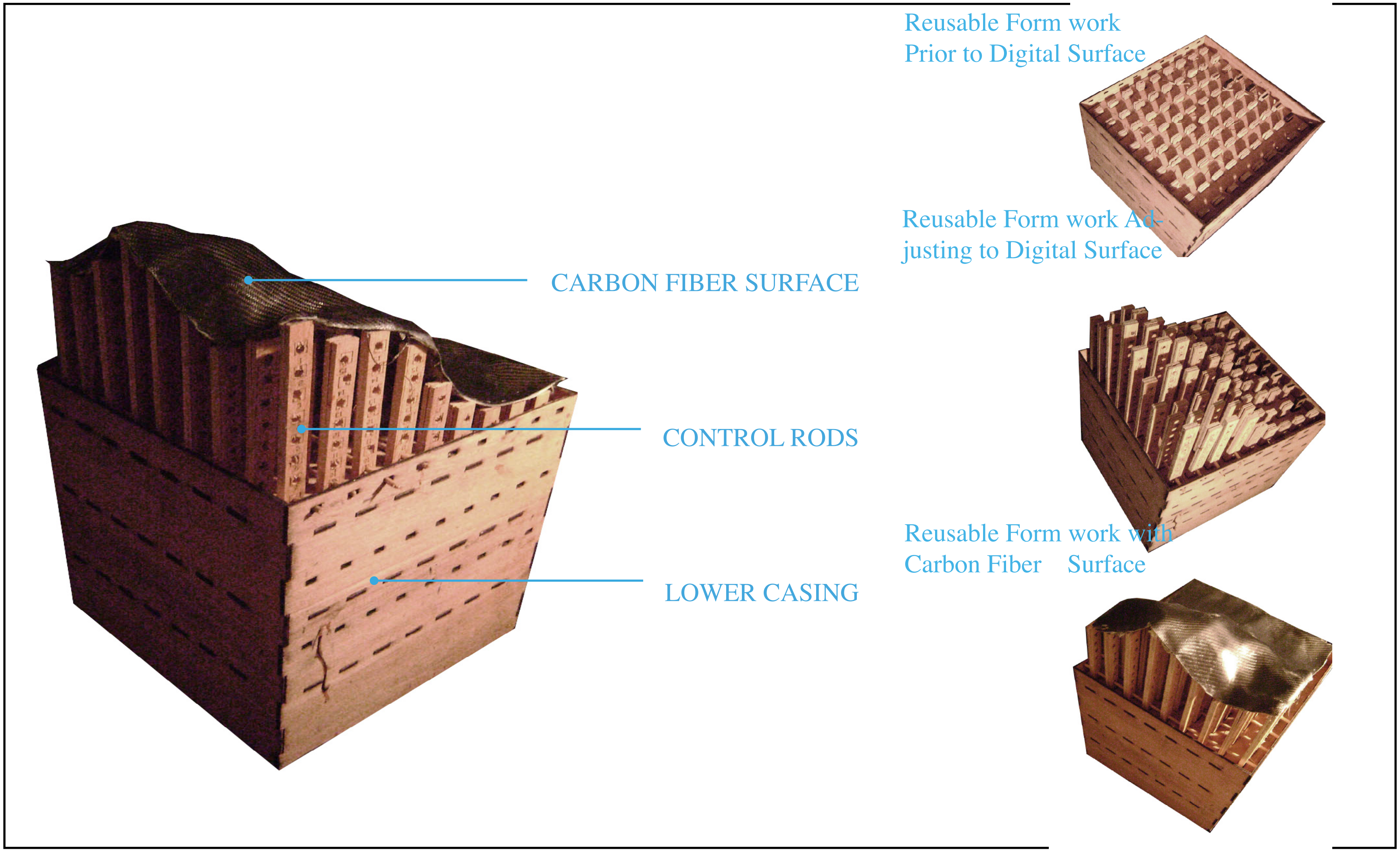


Figure 32. From Digital to Physical - The Reusable Formwork
The reusable form work consists of a box containing the individually controllable rods. The rods can move up based on the geometry of the surface. The carbon fiber is laid over the rods and the desired surface is formed.

Healthy Living Through Bicycling

1. Stay Healthy and Fit

Biking is a great cardiovascular workout and does wonders for circulation and muscle tone. The Centers for Disease Control and Prevention (CDC) recommend that adults engage in moderate intensity physical activity for at least 30 minutes on at least five days of the week. By working bicycling into a daily commute, it is much easier to stay fit. This regular exercise will help control weight, maintain healthy bones, muscles, and joints, reduce the risk of developing high blood pressure and diabetes, and reduce the risk of heart disease.

Figure 33. Staying Fit and Healthy
Bicycling to work is great way to stay healthy and fit because the commute satisfies the CDC's recommendation for physical activity.

2. Save Time

Biking to work is often much quicker than driving. Less time is spent sitting in traffic or looking for parking. Exercising by commuting also saves time from having to go to the gym.

Figure 34. Save Time
Bicycling to work can save time. Often times, bicycle trails bypass traffic congestion and commuters do not have to find parking

3. Save Money

Biking to work is much cheaper than driving. There is no need to pay for gas, insurance, parking, or tickets. Automobiles are expensive to buy and require routine maintenance. The average car owner uses 1/5th of his salary to buy and maintain his car.

Figure 35. Save Money
Bicycling to work saves money by eliminating the cost of an automobile, its maintenance, gas, and parking

4. Have Fun

Biking is lots of fun.   There are many beautiful places to experience.   Riding a bicycle can be less stressful than sitting in the car in traffic. Off-road trails, bike lanes and wide curb lanes allow you to ride past traffic.

[redacted]

Figure 36. Have Fun
Bicycling allows the rider to explore the environment around him more than exploring in a car.

5. Keep Our Planet Green

Biking does not consume fossil fuels, cause ozone depletion, or emit harmful pollutants.

[redacted]

Figure 37. Keep Our Planet Green
Bicycling does not consume fossil fuels, cause ozone depletion, or emit harmful pollutants

Bicycling in DC

The Washington D.C. area is nationally known for the quality and extent of their bicycle trails. With trails extending throughout all of Washington D.C., the city offers a great foundation for further investment in bicycling facilities.

Despite the advantages of bicycling, Washington, D.C. residents bicycle at about the same rate as the nation as a whole. In comparison to the ten largest metropolitan areas in the United States, Washington D.C. ranks eighth. What is even more alarming is that even with rising energy costs, smog, and global warming, the percentage of people driving is growing while the percentage of people bicycling and using public transportation is falling.

	Bicycle Commuting in the Ten Largest Metropolitan Areas	% Bike to Work
1	San Francisco	1.12%
2	Los Angeles	0.63%
3	Boston	0.38%
4	Philadelphia	0.33%
5	Chicago	0.31%
6	Houston	0.30%
7	New York	0.30%
8	Washington	0.30%
9	Detroit	0.18%
10	Dallas--Fort Worth	0.14%
	United States	0.38%

Figure 38. Bicycle Commuting in US Cities
Washington DC score low in the United States for the percentage of bicyclists commuting to work.

There are several reasons why people choose other modes of transportation. In 2004, an event was held called Bike to Work Day. Over 4200 participants rode their bicycle to work for this one day event. Several months later, surveys were sent out to all participants. Asking if they still bicycled to work, and if not why. Of the 354 respondents that did not continue to bicycle to work, 42% cited weather, 35% cited lack of a safe route, 31% cited distance, 18 % cited lack of showers and changing facility, and 10% cited lake of parking. Based on the information from the survey, improvements for bicycle facilities (trails, changing facilities, and parking) would substantially increase bicycling in Washington D.C.[18]

	Reasons for Not Bicycling to Work	%
1	Weather	42%
2	Lack of a Safe Route	35%
3	Distance	31%
4	Lack of Shower/Changing	18%
5	Lack of Parking	10%

Figure 39. Reasons for not Bicycling to Work
Of the reasons for not bicycling most can be addressed through intervention by the city. Between adding safe bicycling routes, showering, changing, and parking, 63 % of the people who chose not to commute would have continued to.

Program

This thesis tests the feasibility of using carbon fiber as a building material on the design of a bicycle station. A bicycle station is a secured and attended area where people can safely leave their bicycles for a short period of time. The bicycle station provides lockers for clothing, showers, and rest room facilities. Because it is located at a destination where commuters converge, whether it be a downtown area or where public transit modes intersect, bicycle stations typically have other program associated with it that appeal to all people.

Because the bicycle station contains program that is repetitive in nature, it naturally fits into the idea of designing with a kit of parts. The bicycle parking, showering, and lockers are all very repetitive elements of the program. The bicycle station allows the testing of this new kit of parts where a series of constraints will help generate the design of the building. Although the elements are repetitive, that does not necessarily dictate that they have to be identical. The constraints will alter the nature of the program so it can respond to a variety of specified conditions.

McDonald's Cycle Center, Chicago, Illinois

At the edge of Chicago's famed "Loop," the two-level, 16,448 square foot station is a draw for bicyclists, runners, and in-line skaters because of its attractive design and setting and convenient downtown location near mass transit, Lake Shore Drive, and a multitude of office buildings. The first full-service bicycle station in Chicago, it offers free daily bicycle parking and a modern locker room facilities for a cost of $1 a day, $15 a month or $90 a year. The Millennium Park Bicycle Station not only provides bicyclists place to park, but also provides a place to get cleaned up. It was designed for the commuter in mind so when someone rides to work, especially in the summer, showers and lockers are available so commuter can be presentable for work.

Up to 300 bikes can be deposited in the heated indoor facility by placing the bicycles on double-stacking racks with a pull-out lever that allows bicyclist to park the bike up to the second level and push it back in. The locker facilities provide 240 lockers for monthly or annual users and 100 pay lockers. The individual showers, four for both women and men, each has a personal dressing area attached, eliminating the corral feel common to many fitness center locker rooms.[19]

[redacted]

Figure 40. McDonald's Cycle Center

Top Aerial view showing the integration of the facility with a parking garage and park. **Middle** Exterior view showing an outdoor seating area. This bicycle facility has program that appeals to non-bicycle users. **Bottom** Interior view showing promenade which goes around the bicycle storage. Users of the facility are always aware of the bicycles. [Muller and Muller]

Proposal for Bicycle Station at Union Station

In Washington DC, there are plans to build a Bicycle Transit Center that will be a peripheral extension to Union Station that offers a alternative transportation option for its users. Union Station is strategically located where thousands of commuters, neighbors and visitors pass through on a daily basis. The plan is for the center to serve as a catalyst to stimulate bicycle use and alternative transportation means as an extension to the existing transit modes at Union Station. The designers want the facility to take advantage of its prominent location and become a visible transportation model as well as a focal center for the bicycle community. The design calls for a 1750 sqft structure that purposes secure parking for 180 bicycles, non-secure parking for 20 bicycles, short-term parking for 10 bicycles, changing rooms, 40 short and long-term lockers, a retail area, and storage.[20]

[redacted]

Figure 41. Plan of Proposed Union Station Bicycle Station
Plan is divided into two areas. One side is the bicycle storage and parking. The other side is the retail and bicycle shop.
[dc.gov]

[redacted]

Figure 42. Perspective of the Bicycle Station
View showing vehicular between bike station and Union Station.
[dc.gov]

[redacted]

Figure 43. Brochure and Images for the Bike Station Long Beach
Bikestation is a nonprofit organization that offers secure parking and other services for bicyclists. This brochure for Bikestation Long Beach shows all the amenities and services provided by the bicycle station including parking, renting, repair, and food as well as shows how it connects to other forms of transportation.[21] [Bikestation.org]

Prototype Program Requirements

Bicycle Parking for 100 +bicycles ....1000 sf
Provides protection from theft, vandalism, and the weather. Should be designed so it can easily expand.

Shower and Locker ....500 sf
Lockers large enough for storage of business clothes
Showers and Rest rooms (10+)

Bicycle Shop/Service ....500 sf
Provide maintenance and service for bicycles
Provide space for the sale of bicycling gear and parts

Cafe/Coffee Shop ....1000 sf
Easy access to all people using metro
Indoor seating with the possibility for outdoor seating when seasons permit

Newspaper ....0 sf
Projected on the façade (real-time news)

Figure 44. Prototype Program Requirements
The design requirements based on ideal prototype program

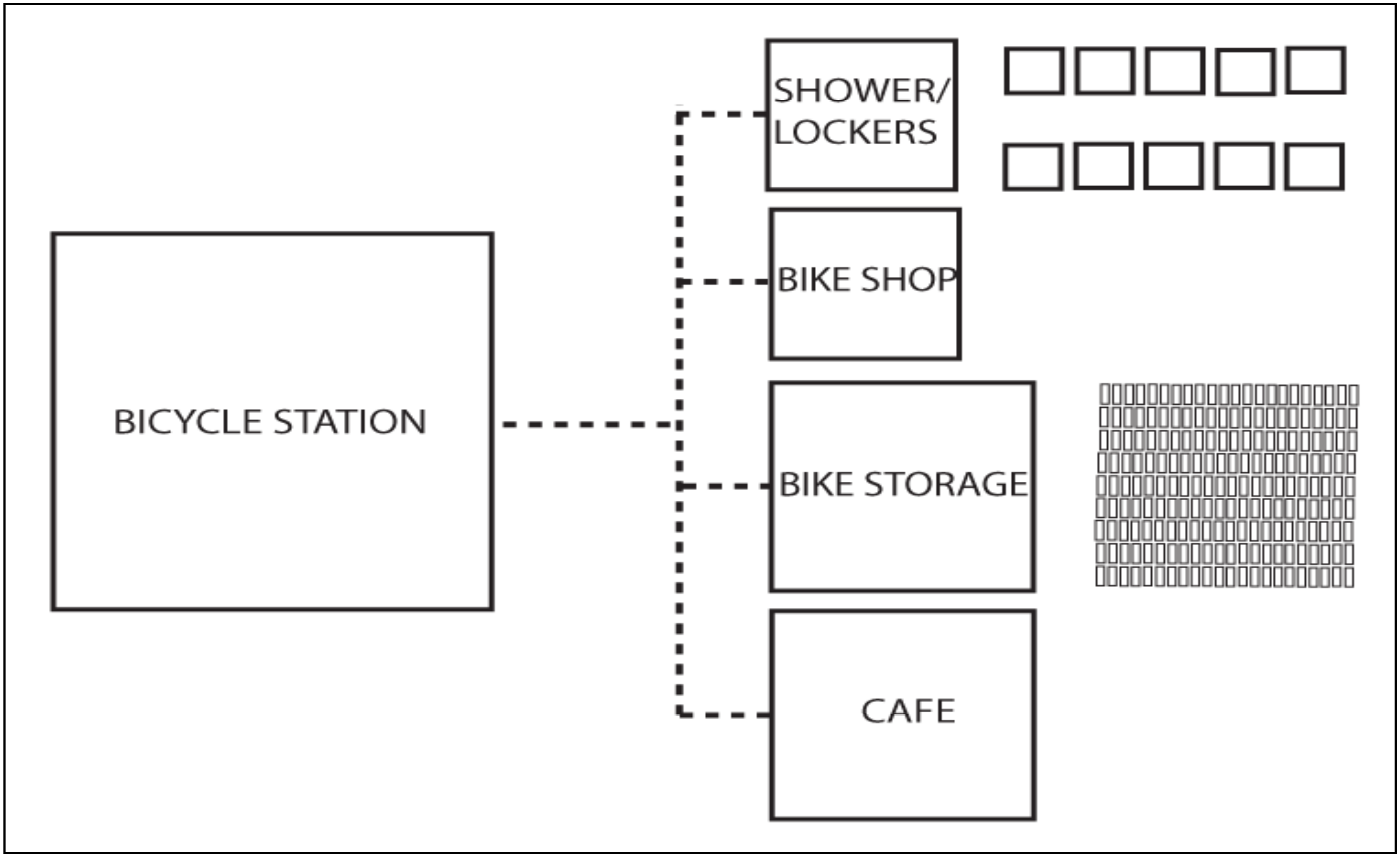


Figure 45. Program Diagram
The bicycle station is composed of four major areas. The four areas include Shower/Locker, Bike Shop, Bike Storage, and Cafe.

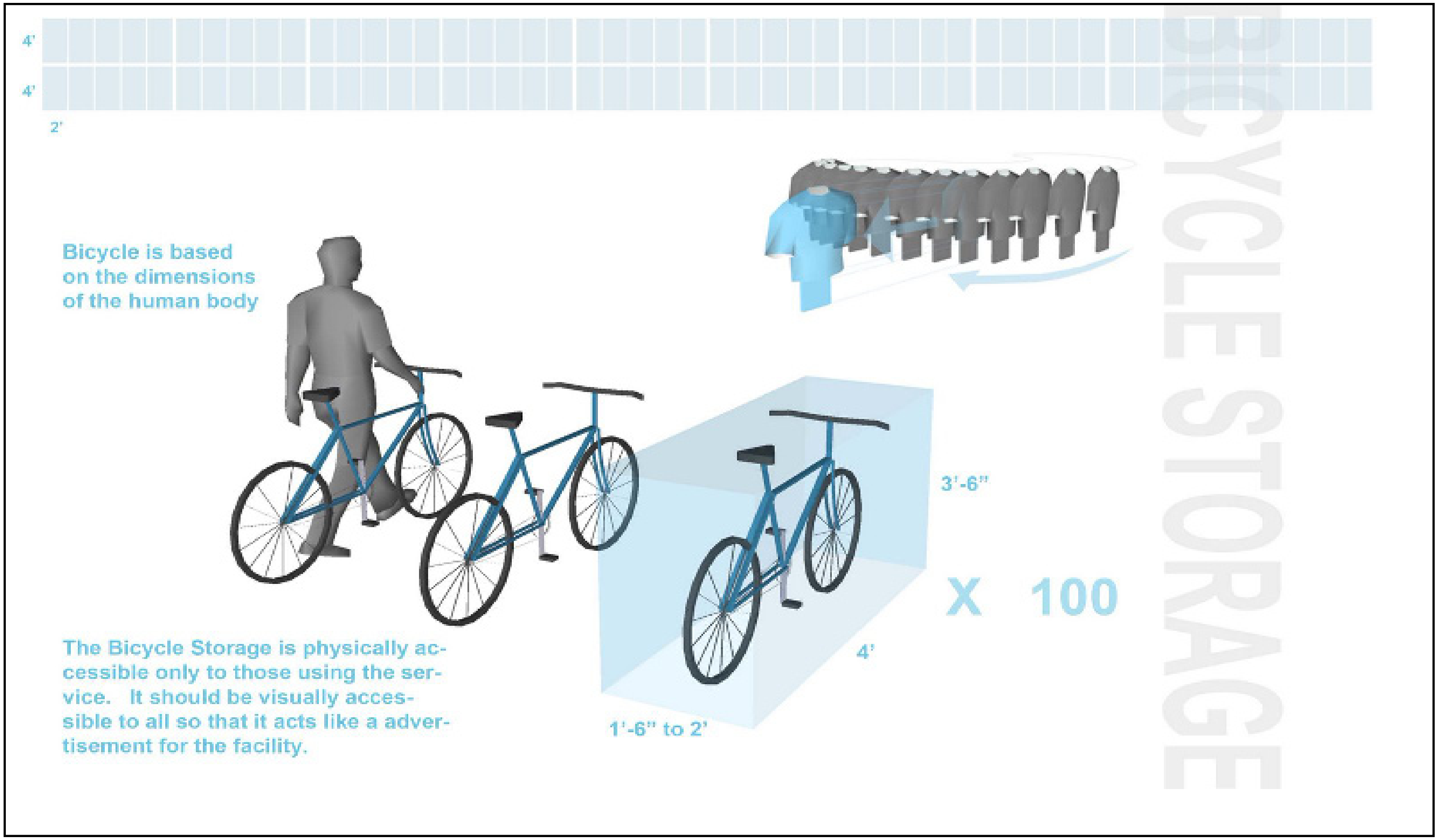


Figure 46. Program -Bicycle Storage
The bicycle storage is based on the dimension of the bicycle. The bicycle rack will be similar to that of a clothes rack at a dry cleaner. Bicycles are inserted in from one location and filed away in the storage area. The storage area will be visually accessible but not physically accessible.

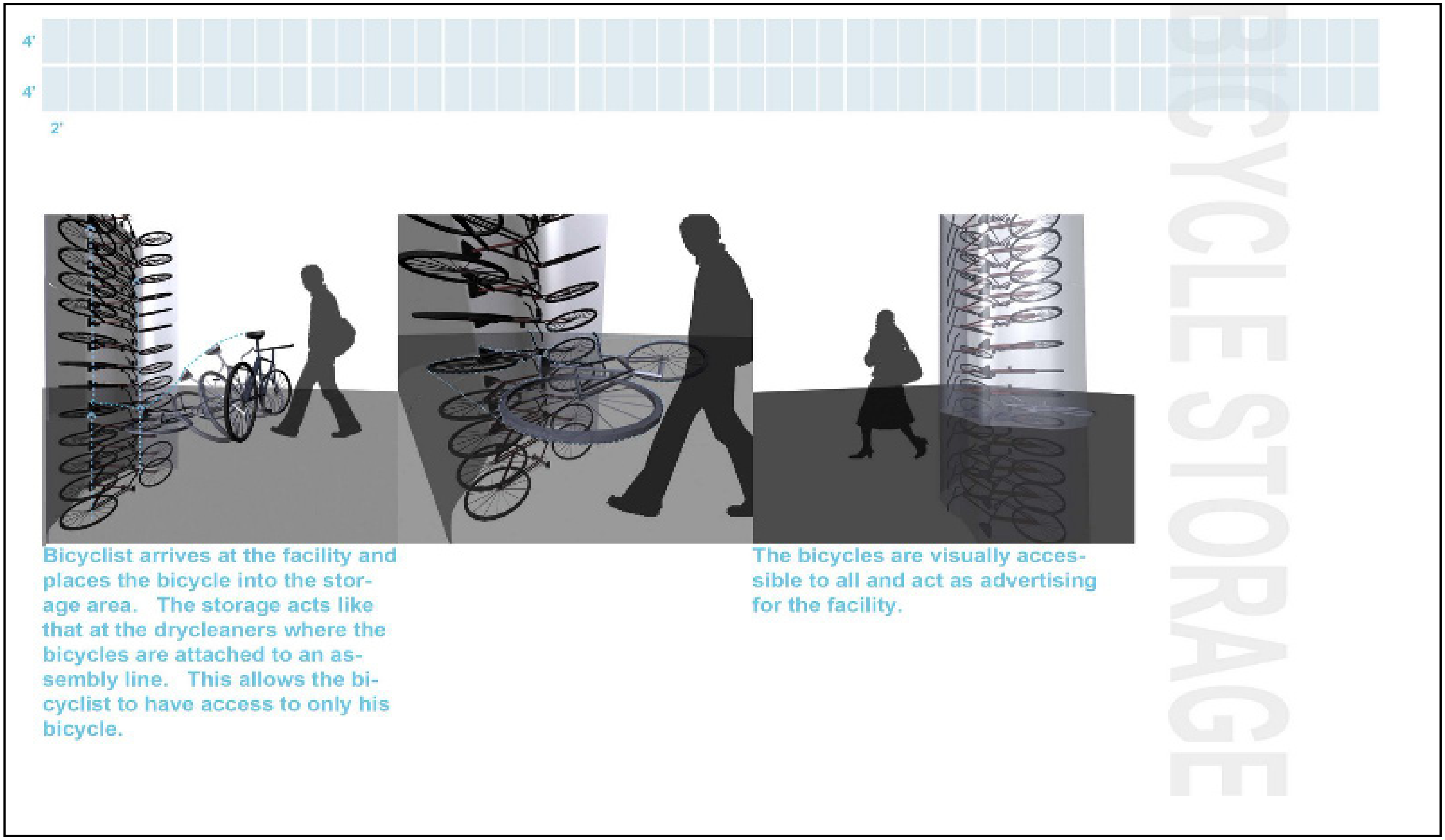


Figure 47. Program -Bicycle Storage

The bicycle storage is based on the dimension of the bicycle. The bicycle rack will be similar to that of a clothes rack at a dry cleaner. Bicycles are inserted in from one location and filed away in the storage area. The storage area will be visually accessible but not physically accessible.

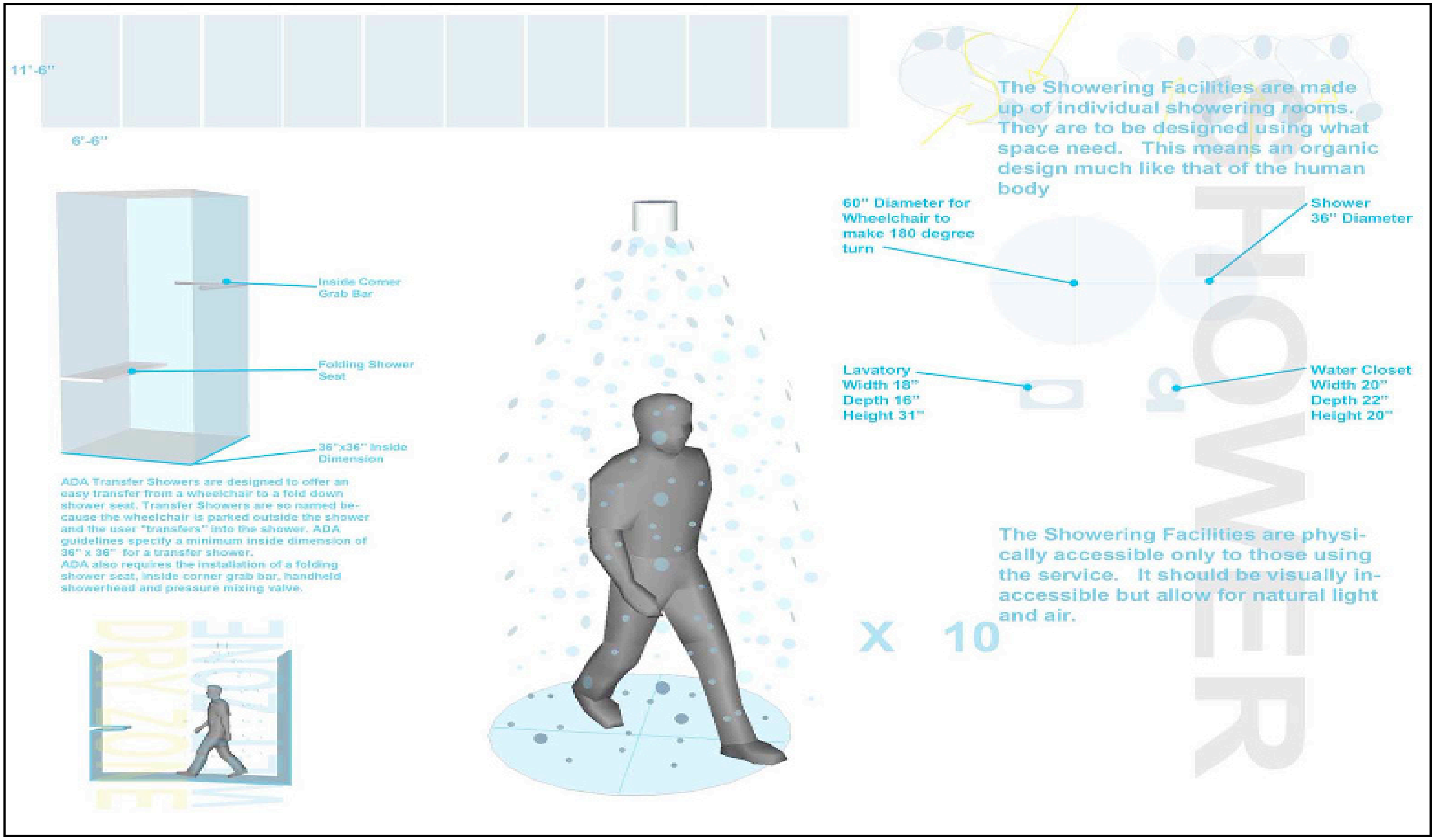


Figure 48. Program -Shower

The shower is based on the dimension of the human and is designed based on the program required for a shower. The shower is divided into a wet zone and dry zone. The shower is designed to be made of a kit of parts that is assembled and inserted into the bicycle station as individual units.

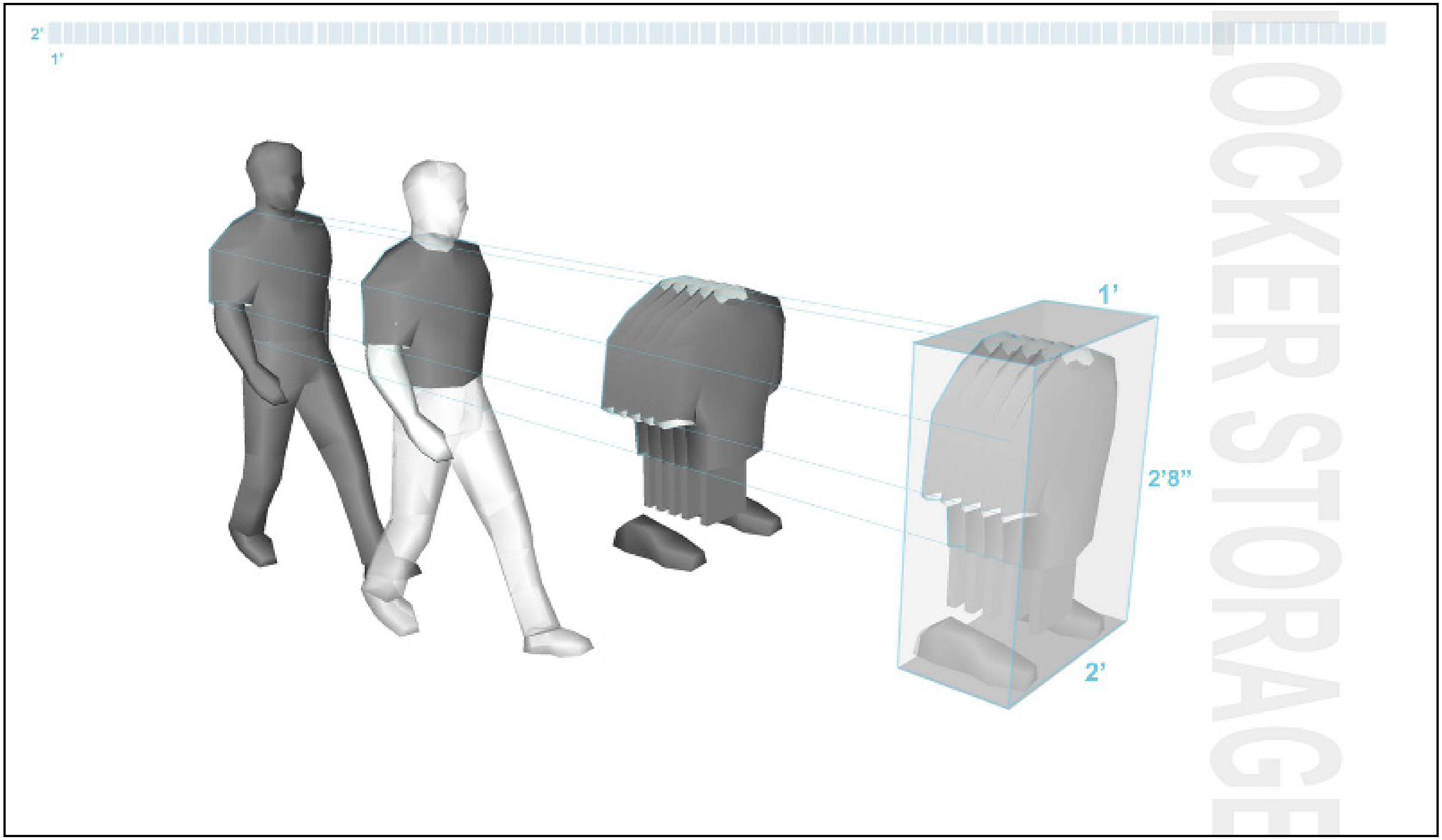


Figure 49. Program -Lockers
The locker is based on the dimension of typical office clothing (suit, shirt, pants, shoes) and is designed to hold clothing for five days.

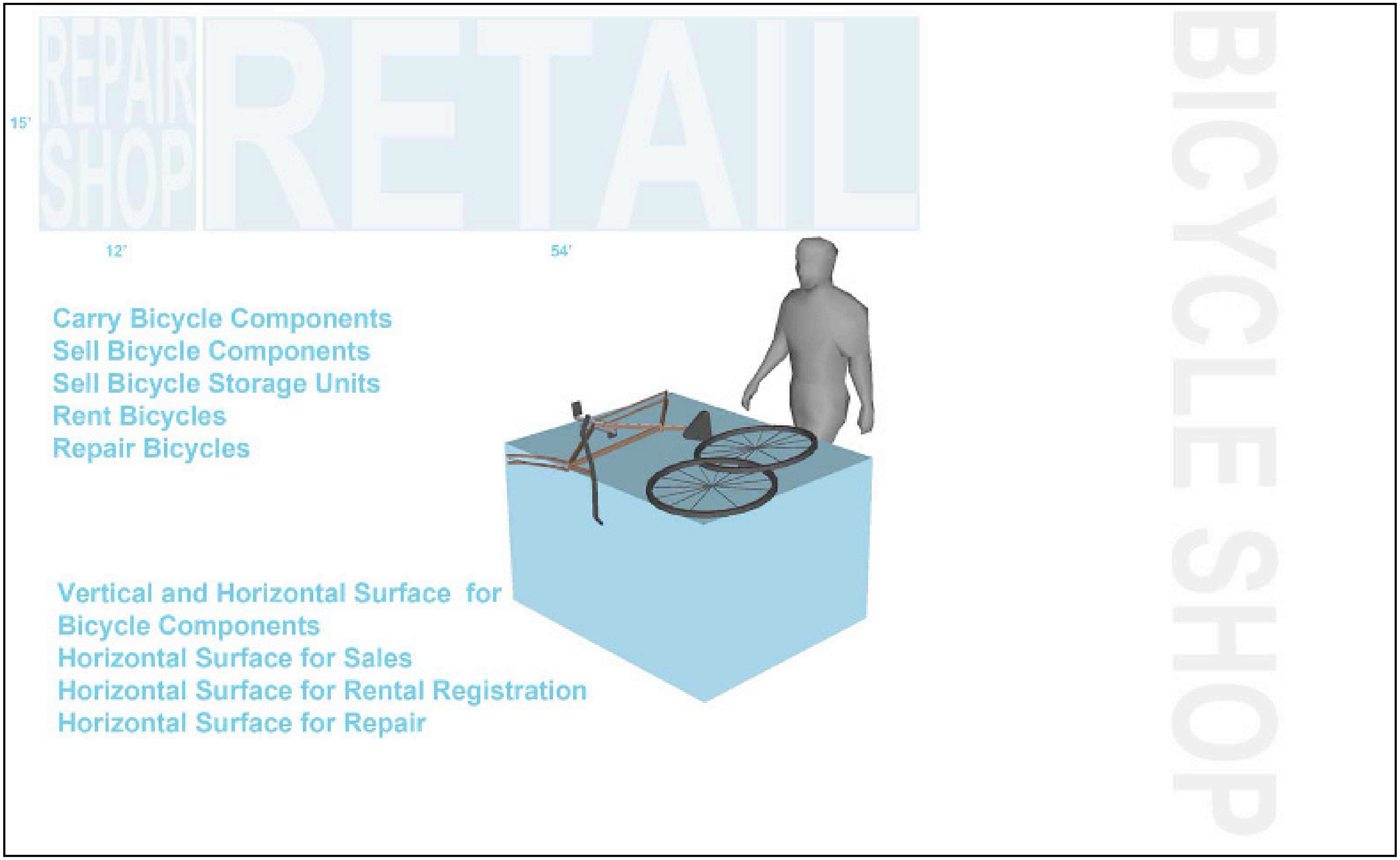


Figure 50. Program -Shop

The shop is designed based on the dimensions of both the human and the bicycle. It is divided into two areas- repair and retail.

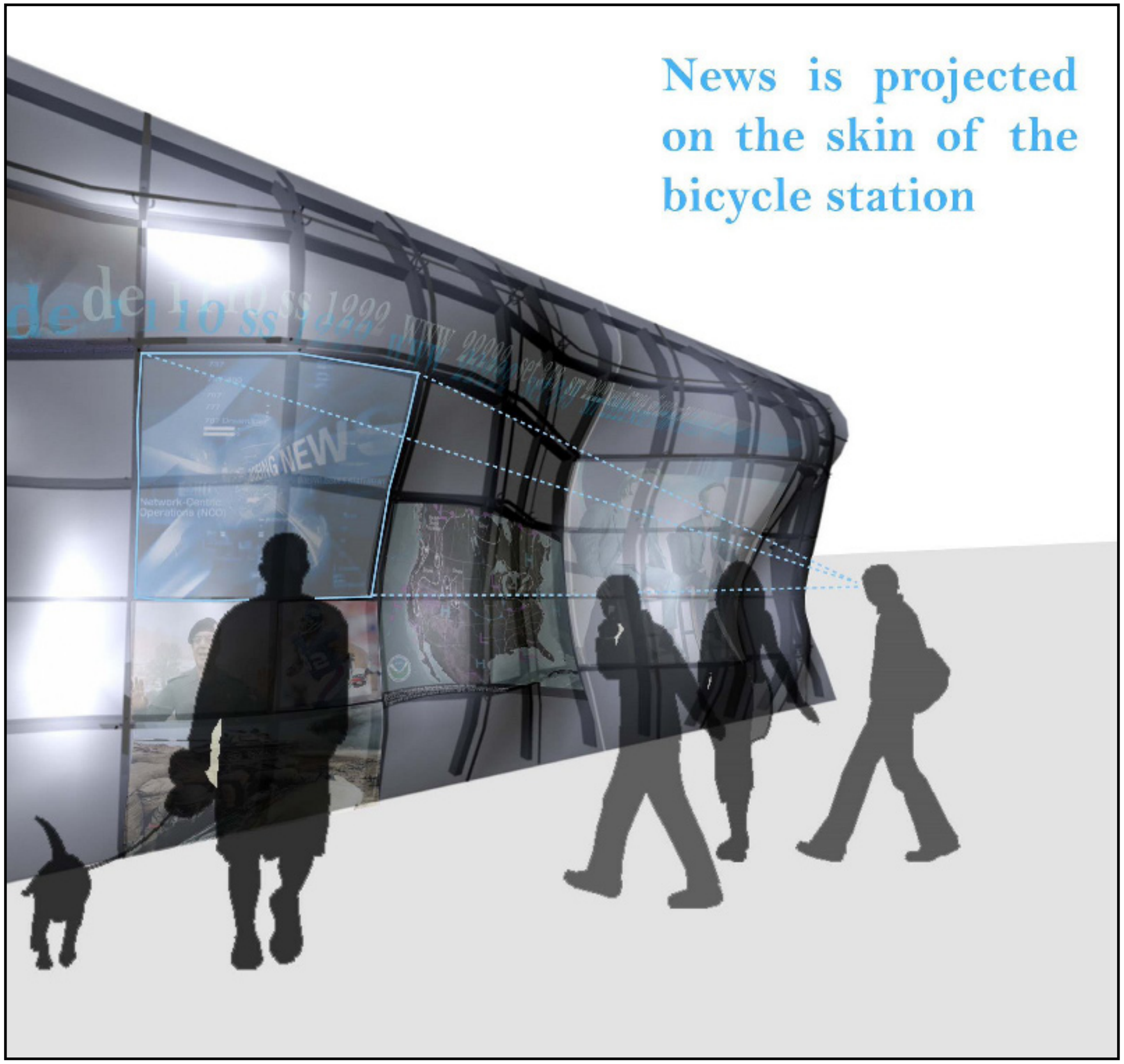


Figure 51. Program -News
The news is projected on the skin of the building for people walking to see.

Figure 52. Greg Lynn's Encore Buxelles Project was a design for an installation where the images are projected on the curved surfaces. [Greg Lynn Form]

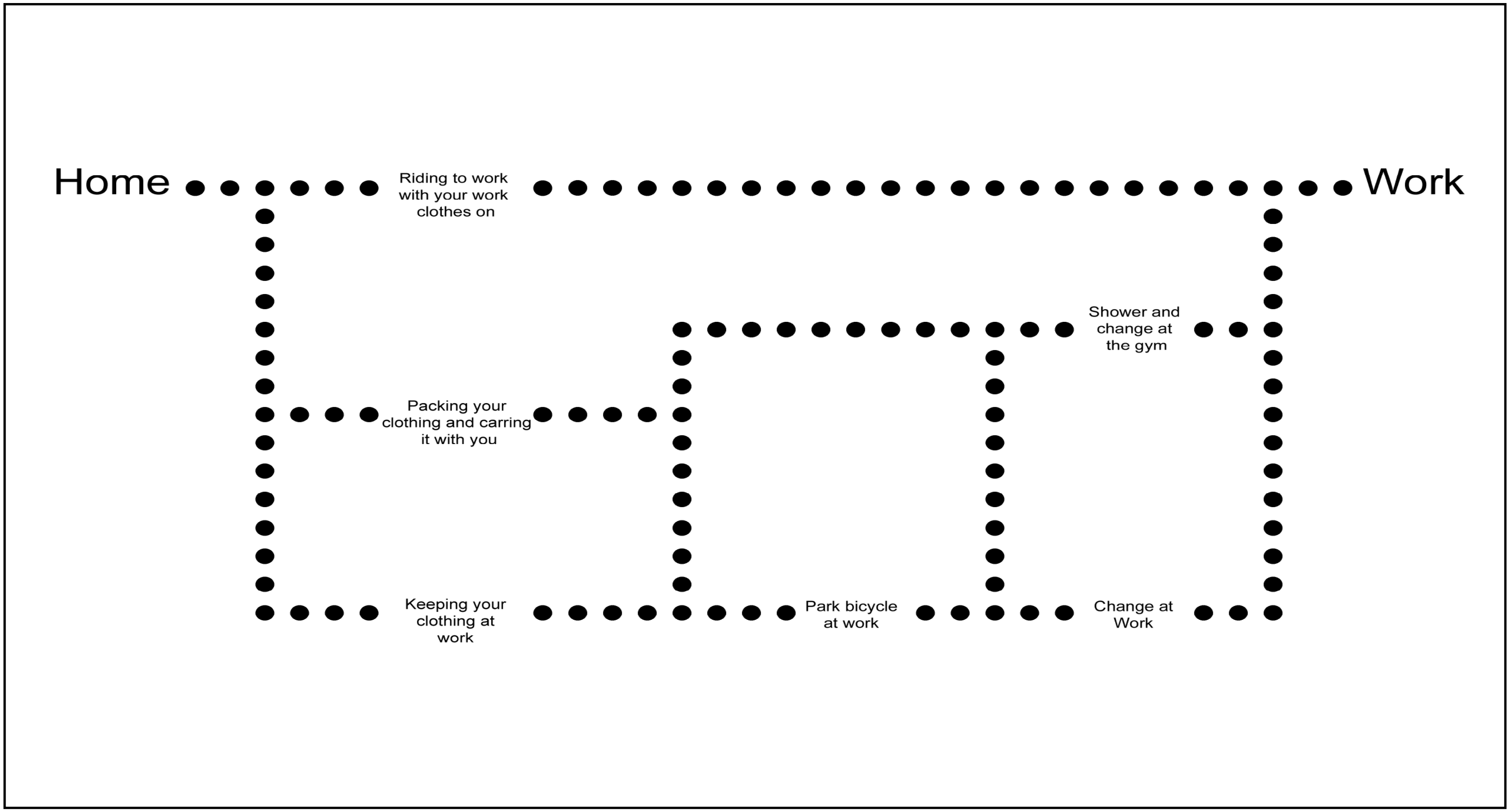


Figure 53. Possible Situations to Commute to Work

Diagram describing possible scenarios a bicycle commuter could face while biking to work. It first describes possible scenarios based on where a commuter stores his clothing. The next scenario is where the commuter parks his bicycle. The final scenario is where commuter showers and changes. This analysis starts to indicate locations for a bicycle station and what program should be in it. If a gym is close to a downtown district, the bicycle station may only have parking and no showering and changing area.

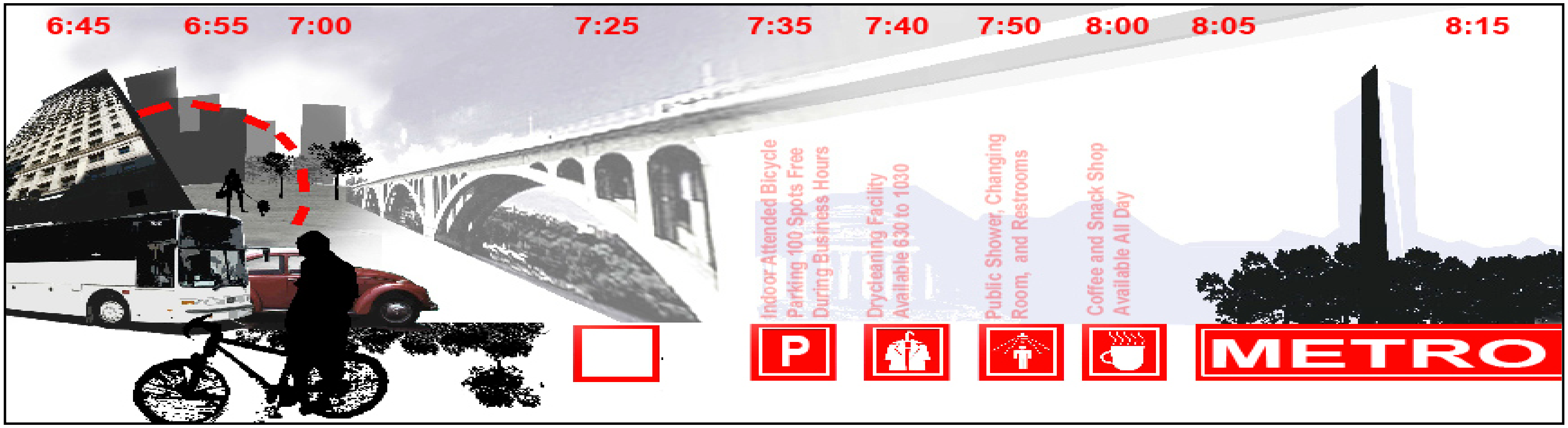


Figure 54. Typical Commute to Work

Typical scenario of a bicycle commuter . The commuter would leave his home by bicycle and commute to the bicycle station. There the commuter would park his bicycle, pick up his clothes from either the dry cleaner or from his locker, and take a shower. After showering he would get breakfast and go to work.

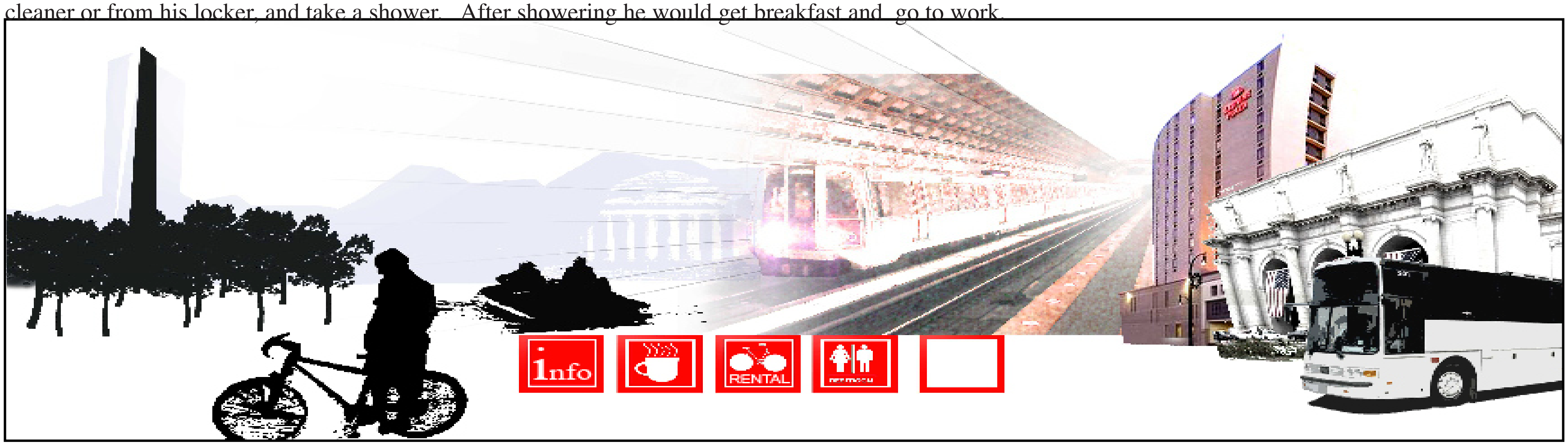


Figure 55. Typical Services for the Renter

The bicycle station is also a rental facility for people who want to see Washington DC by bicycle. It offers information on bicycling in the city as well as provides food and rest room facilities.

Criteria for the Site Selection Process

- Ideal Urban Conditions
  - Rental
  - Commuter
- Density
  - Bicycle parking at the Metro
  - Bicycle Commuting in Neighborhood
  - People in Neighborhood
- Location
  - Metro
  - Marc
  - Park
  - Business
  - Residential
- Trails
  - Quality of Trails in the Area

Figure 56. Bicycle Siting Selection Criteria
List of criteria based on ideal urban conditions, location, density, trails, and site conditions.

Figure 57. East Coast Greenway
The East Coast Greenway is a bicycle trail that runs from Canada to Key West and connects all the major east coast cities in between. Washington DC is located along the East Coast Greenway.

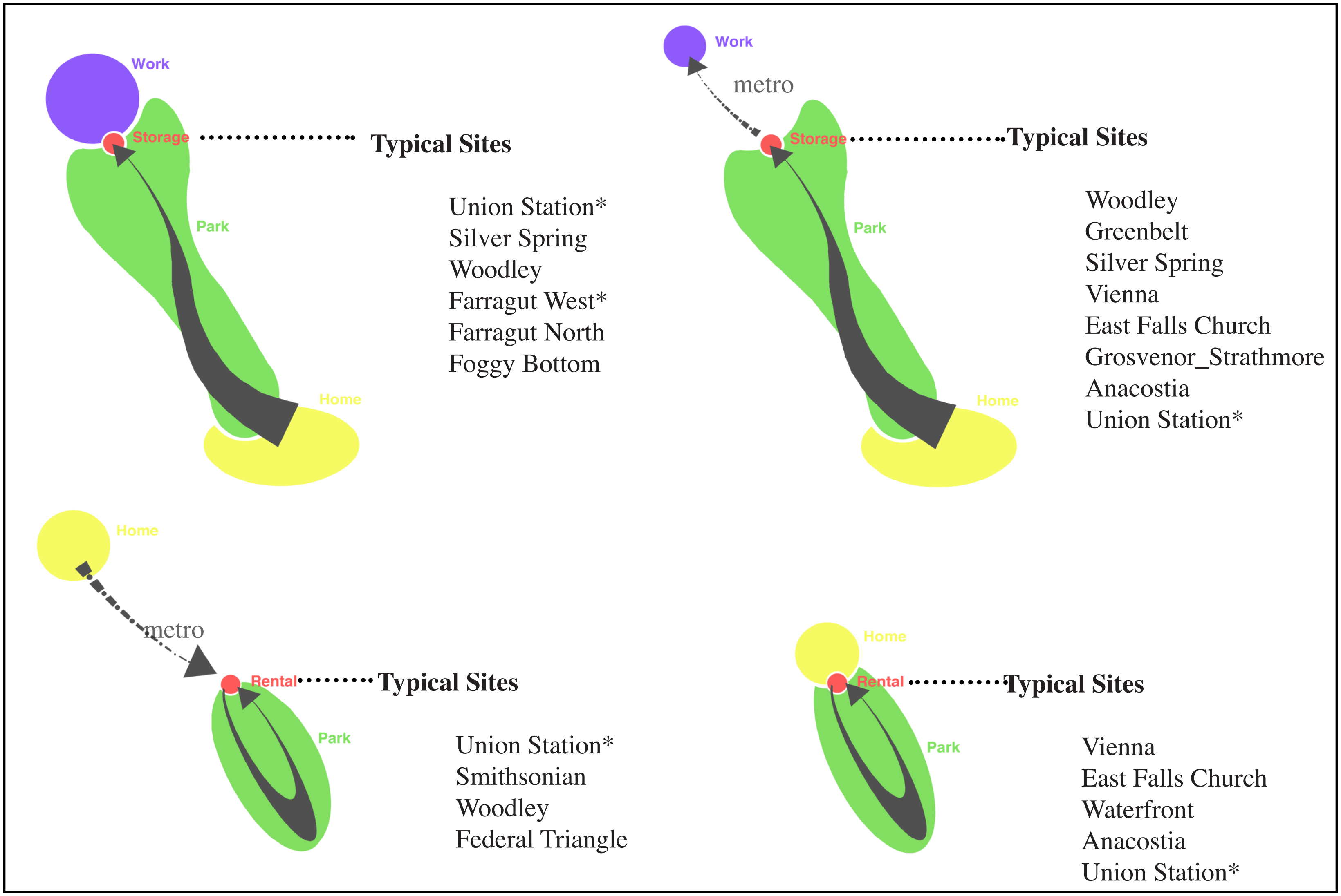


Figure 58. Ideal Siting Conditions for Bicycle a Station

Ideal site conditions for a bicycle station used primarily as storage and primarily as rental. Based on the ideal conditions a series of potential sites are indicated at metro stations.

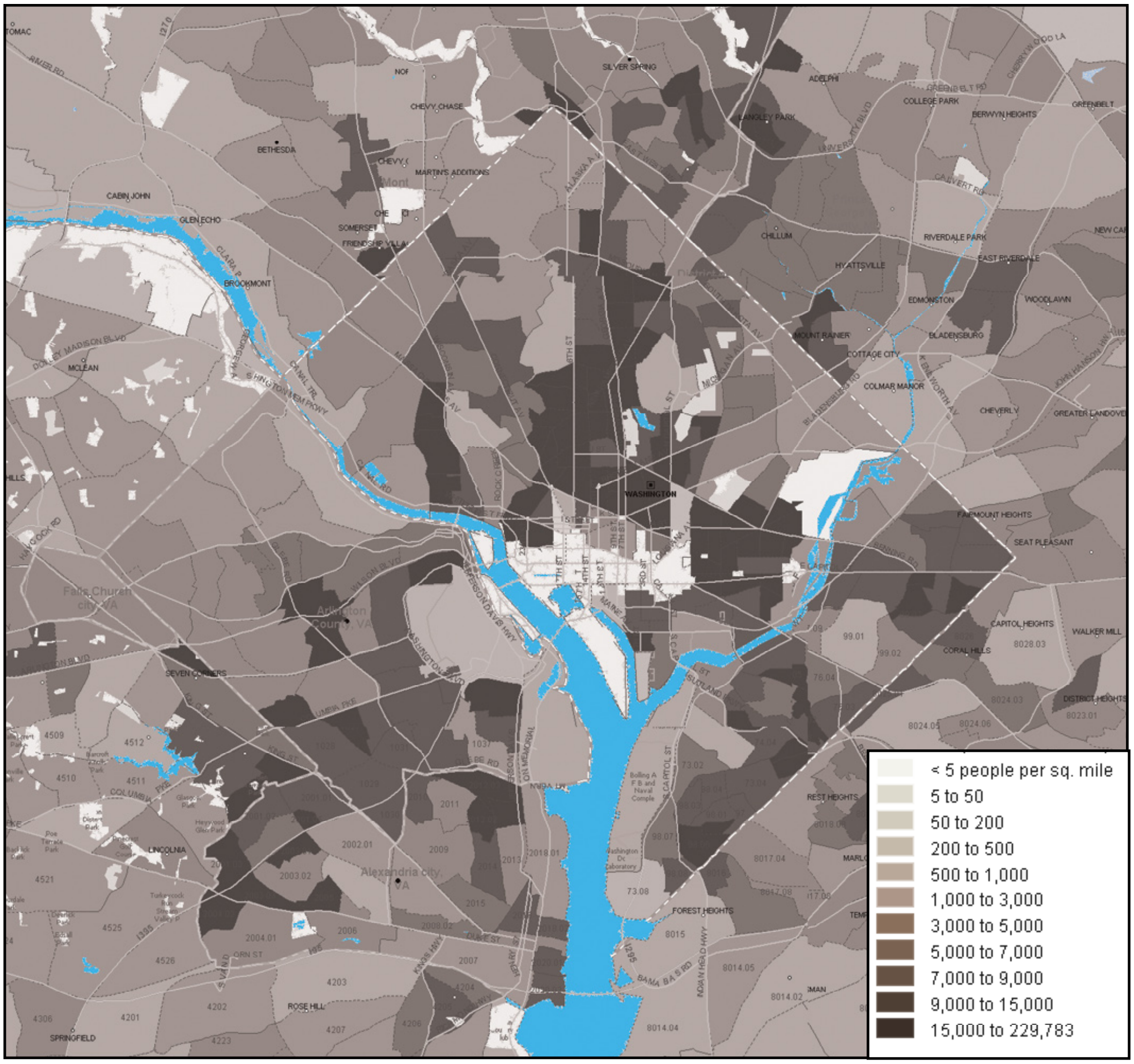


Figure 59. Population Density

Most of the population in the Washington DC area is located just east and west of Rock Creek Park, east of the Mall, and in west of the Potomac River in Virginia. [Social Explorer]

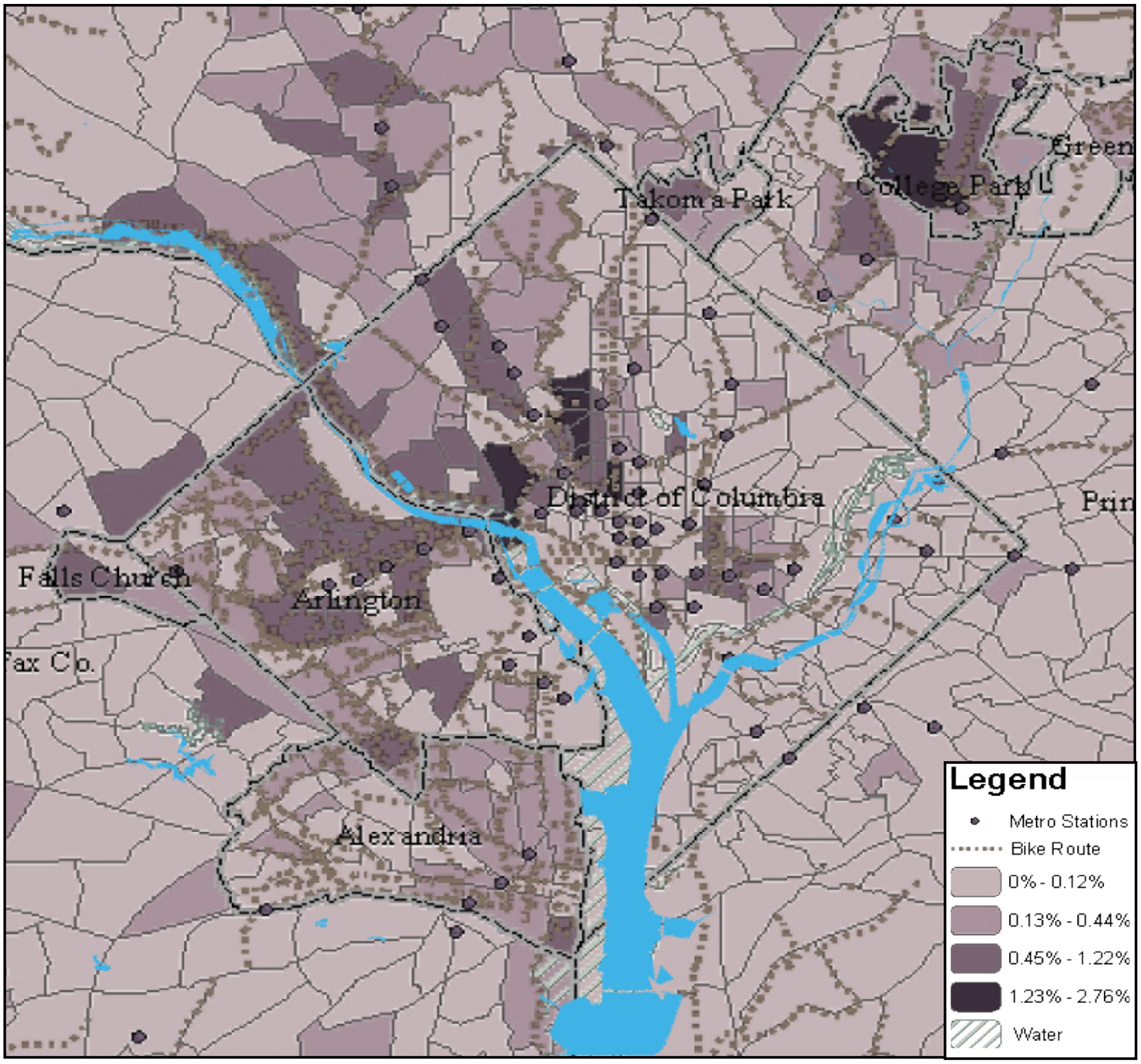


Figure 60. Bicycle Commuter Population Density

Most of the population of bicycle commuters in the Washington DC is located west of the Rock Creek Park, west of the Potomac River in Virginia, and in the College Park/Greenbelt Area. [dc.gov]

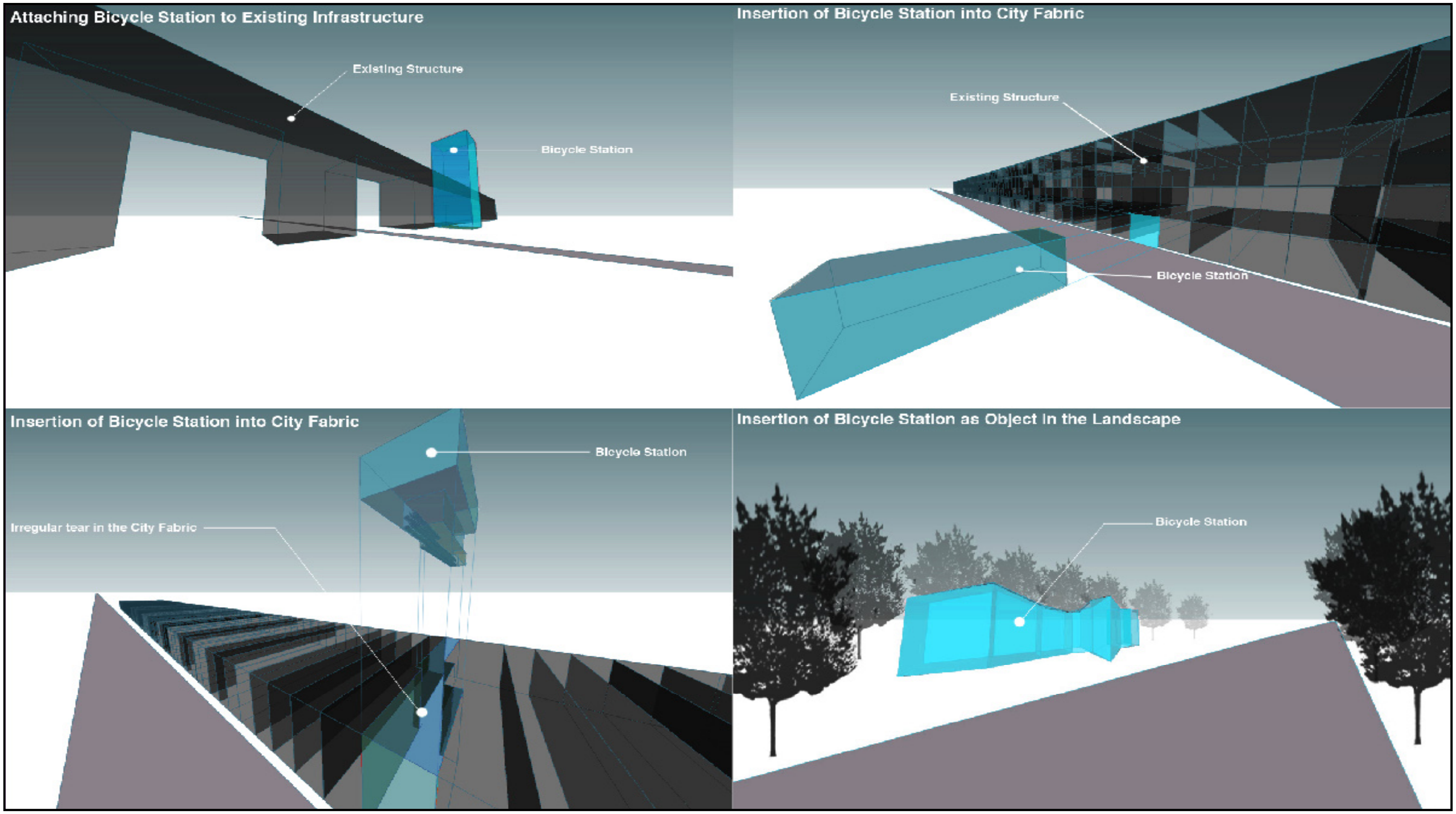


Figure 61. Various Urban Conditions for Locating Bicycle Station -
The bicycle station is tested on various urban conditions. Each condition raises different issues of scale. Top left shows the station being attached to existing infrastructure. The top right shows the station being inserted into an existing building. The bottom left shows the station being inserted into a tear in the urban fabric. The bottom right shows the bicycle station as a free standing object in the landscape.

STATION	JURISDICTION	TOTAL LOCKERS	USED LOCKERS	PERCENT	TOTAL RACKS
Addison Road-Seat Pleasant	Prince George's				18
Anacostia	DC	8	4	50%	13
Archives-Navy Mem'l-Penn Quarter	DC				
Arlington Cemetery	Arlington County				
Ballston-MU	Arlington County				54
Benning Road	DC				4
Bethesda	Montgomery	44	43	98%	48
Braddock Road	Alexandria	12	11	92%	46
Branch Ave	Prince George's	24	5	21%	10
Brookland-CUA	DC	16	9	56%	10
Capitol Heights	Prince George's				6
Capitol South	DC				
Cheverly	Prince George's				34
Clarendon	Arlington County	6	5	83%	12
Cleveland Park	DC	12	12	100%	16
College Park-U of Md	Prince George's	40	17	43%	89
Columbia Heights	DC	12	4	33%	4
Congress Heights	Prince George's	12	2	17%	10
Court House	Arlington County				20
Crystal City	Arlington County				10
Deanwood	DC				6
Dunn Loring-Merrifield	Fairfax County	34	22	65%	40
Dupont Circle	DC	12	7	58%	16
East Falls Church	Arlington County	36	23	64%	88
Eastern Market	DC	20	17	85%	
Eisenhower Ave	Alexandria	6	4	67%	10
Farragut North	DC				8
Farragut West	DC				4

STATION	JURISDICTION	TOTAL LOCKERS	USED LOCKERS	PERCENT	TOTAL RACKS
Federal Center SW	DC				2
Federal Triangle	DC				20
Foggy Bottom-GWU	DC	20	11	55%	10
Forest Glen	Montgomery	16	13	81%	42
Fort Totten	DC	6	1	17%	10
Franconia-Springfield	Fairfax County	20	16	80%	37
Friendship Heights	DC	22	21	95%	44
Gallery Pl-Chinatown	DC				
Georgia Ave-Petworth	DC	12	1	8%	
Glenmont	Montgomery	48	17	35%	36
Greenbelt	Prince George's	52	38	73%	60
Grosvenor-Strathmore	Montgomery	30	22	73%	40
Huntington	Fairfax County	12	7	58%	34
Judiciary Sq	DC				13
King Street	Alexandria	20	10	50%	34
L'Enfant Plaza	DC				
Landover	Prince George's	8	1	13%	26
Largo Town Center	Prince George's	48	4	8%	9
McPherson Sq	DC				1
Medical Center	Montgomery	38	34	89%	88
Metro Center	DC				4
Minnesota Ave	DC	4	0	0%	8
Morgan Boulevard	Prince George's	40	0	0%	9
Mt Vernon Sq/7th St-Convention Center	DC				6
Navy Yard	DC				12
Naylor Road	Prince George's	4	0	0%	10
New Carrollton	Prince George's	16	9	56%	18
New York Ave-Florida Ave-Gallaudet U	DC	28	3	11%	10
Pentagon	Arlington County				6
Pentagon City	Arlington County	22	13	59%	8
Potomac Ave	DC				21
Prince George's Plaza	Prince George's	24	4	17%	40
Rhode Island Ave-Brentwood	DC				14

Figure 62. Metro Bicycle Parking

Shows the total number of bicycle lockers available and used. There tends to be no parking in the commercial district of Washington DC. There tends to be more parking at metro stations in Maryland and Virginia.

[wmta.com]

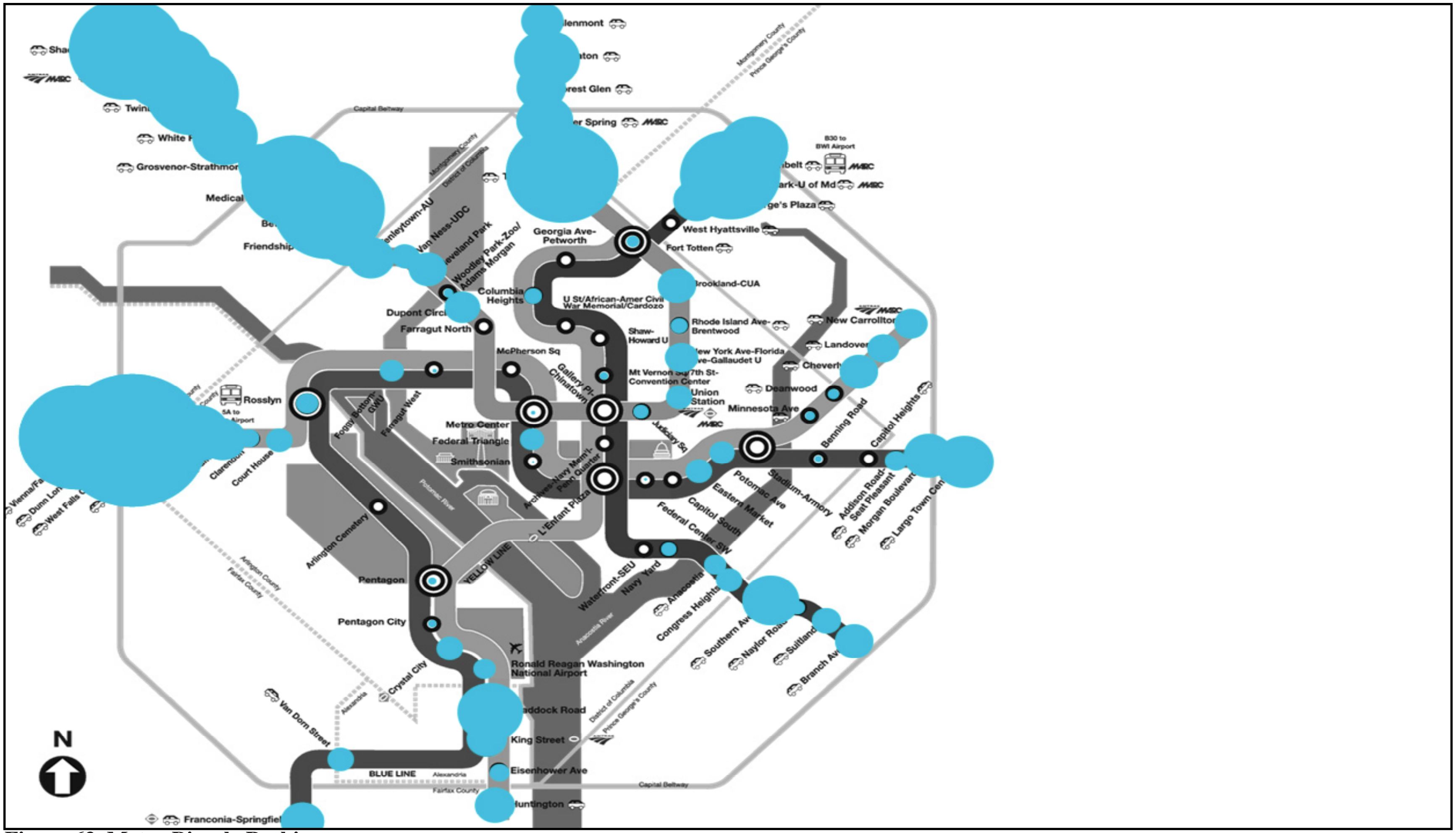


Figure 63. Metro Bicycle Parking

Shows the total number of bicycle lockers available. The larger the dots the more spaces are available. There tends to be no parking in the commercial district of Washington DC. There tends to be more parking at metro stations in Maryland and Virginia. This shows a potential need for bicycle parking in the commercial core of Washington DC.

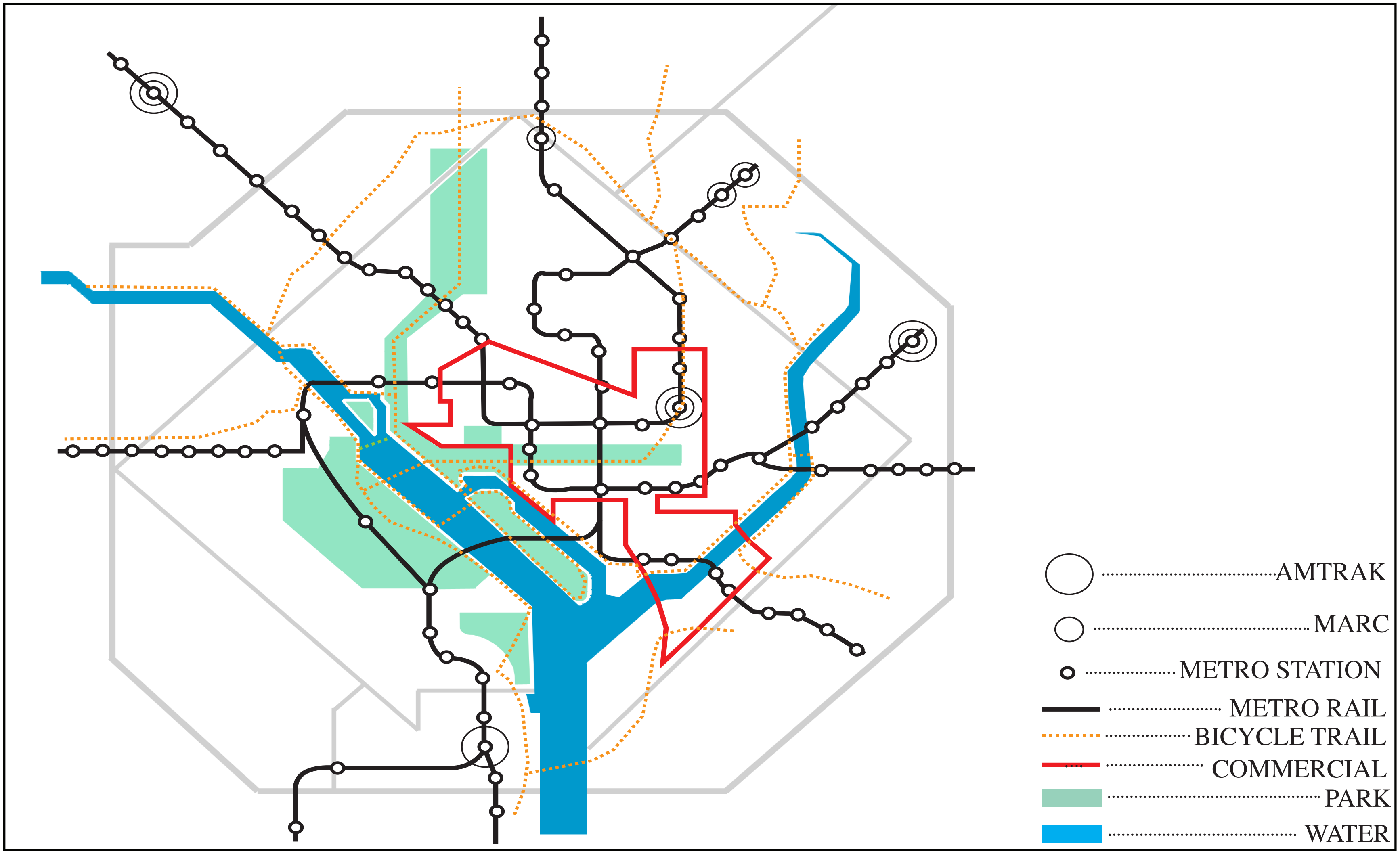


Figure 64. Transportation
Diagram showing various forms of transportation systems in Washington DC and their relationship to parks, commercial district, and water.

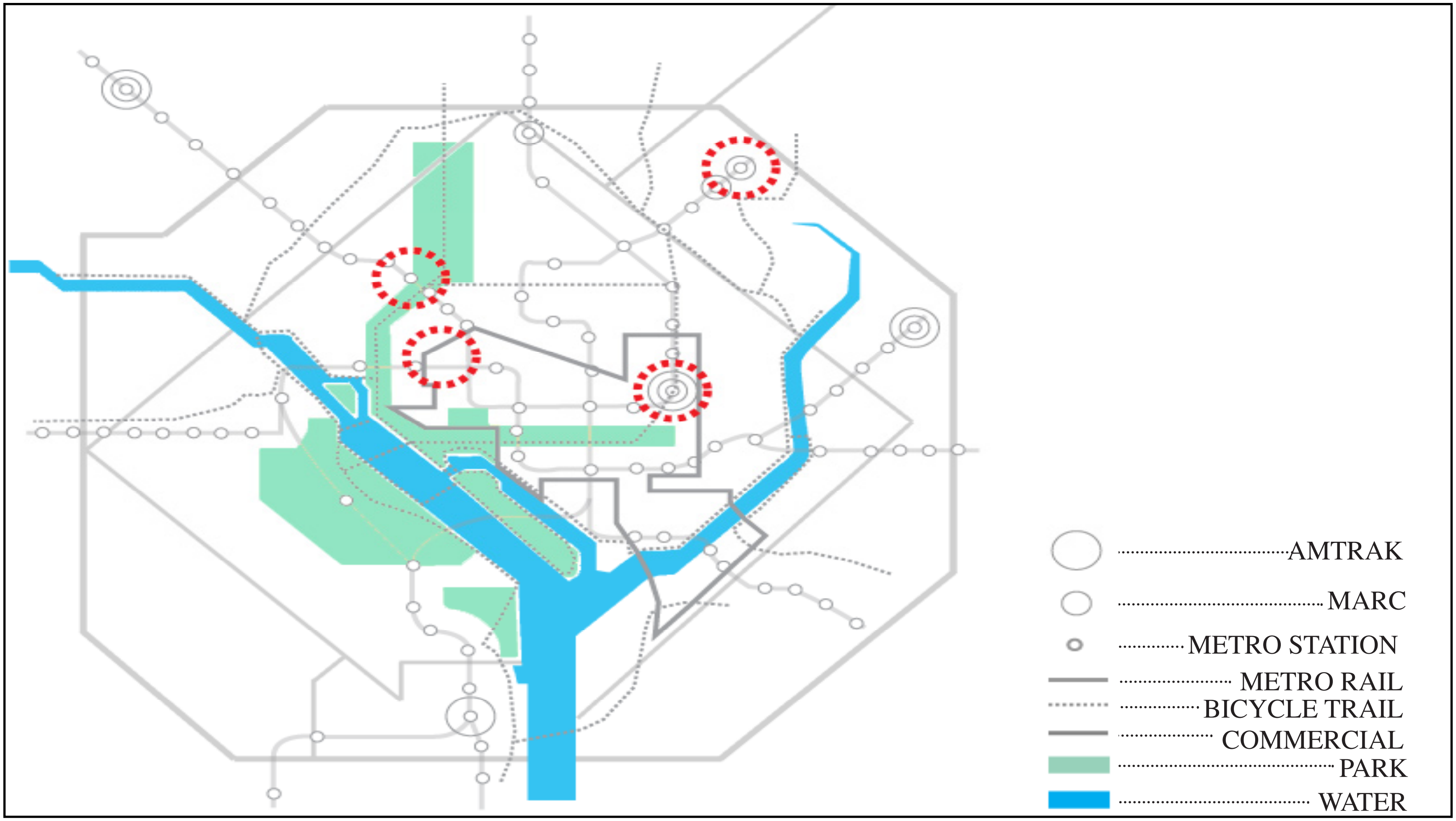


Figure 65. Site Selection

Sites are indicated based on ideal site conditions, bicycle commuter density, transportation analysis, and parking analysis. Woodley Park is identified because its density and its location to Metro, the park, and trails. Farragut Square identified because of its location to Metro, park, trails, and commercial district. Union Station identified because of its location to Metro, Marc, Amtrak, park, trails, and commercial district. Greenbelt identified because of its density and its location to Metro, Marc, park, and trails.

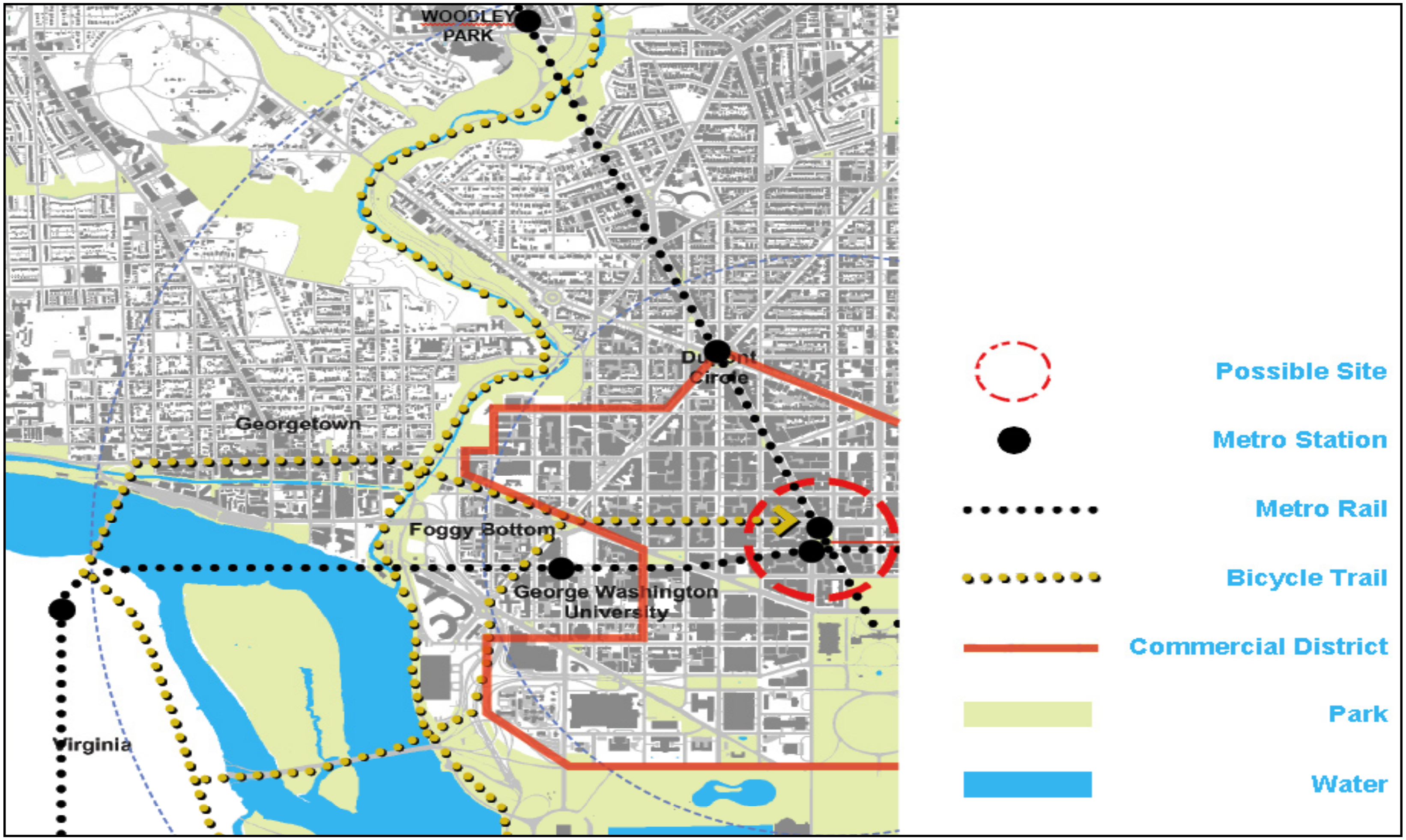


Figure 66. Farragut Square

Farragut Square is a park located on the western edge of the Washington DC commercial district. It is also serviced by three metro rails (red, blue, and orange). A growing population of Virginia residents are commuting to Washington DC through the Canal Tow Path and Farragut Square is the closest commercial area to that trail. Siting a bicycle station here would create parking for bicycles in a location where no parking currently exists.

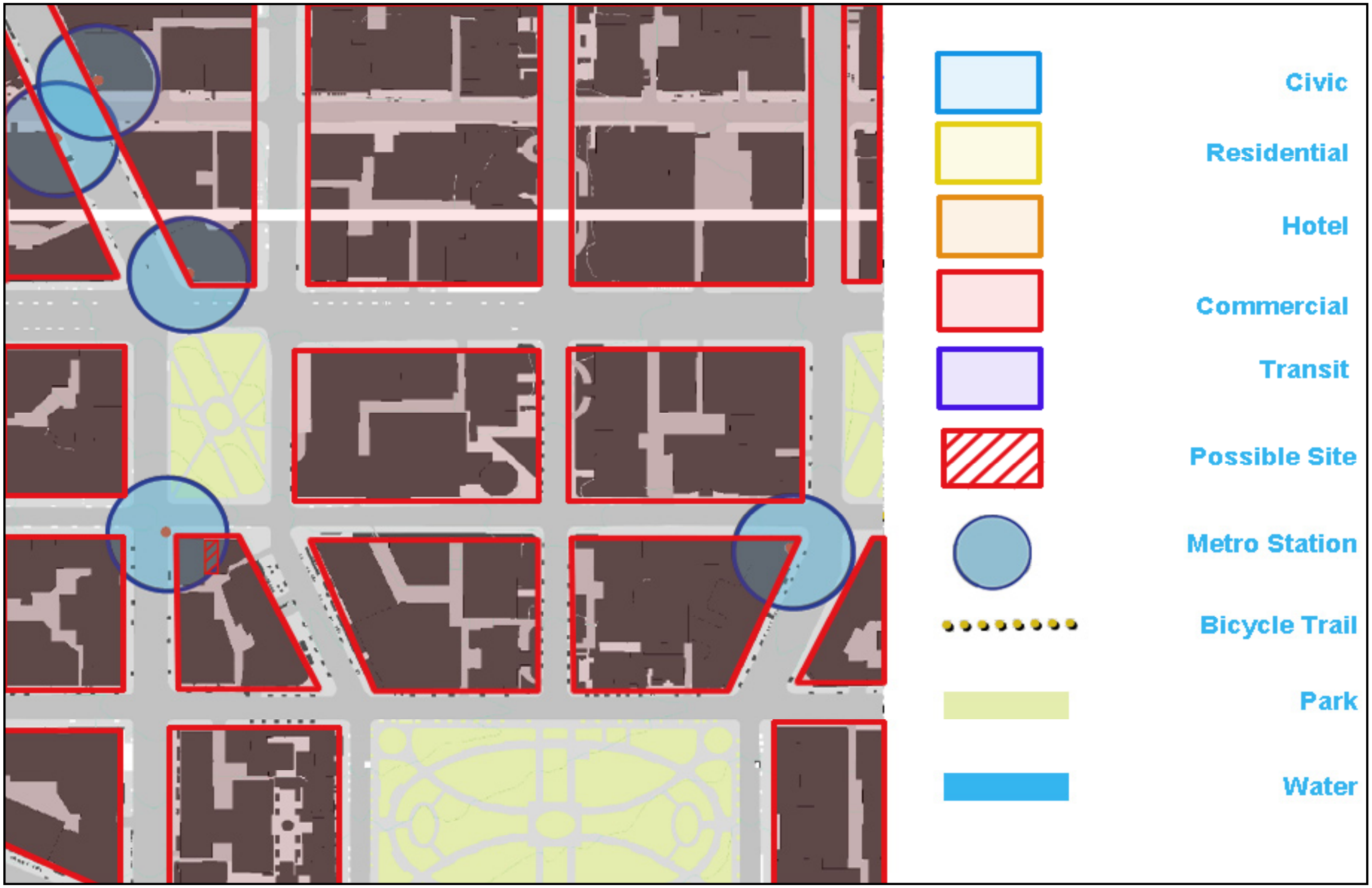


Figure 67. Farragut Square

Several metro entrances are located near Farragut Square. The area is surrounded by commercial buildings and there is currently no bicycle trails. Commuters have to bike on the street.

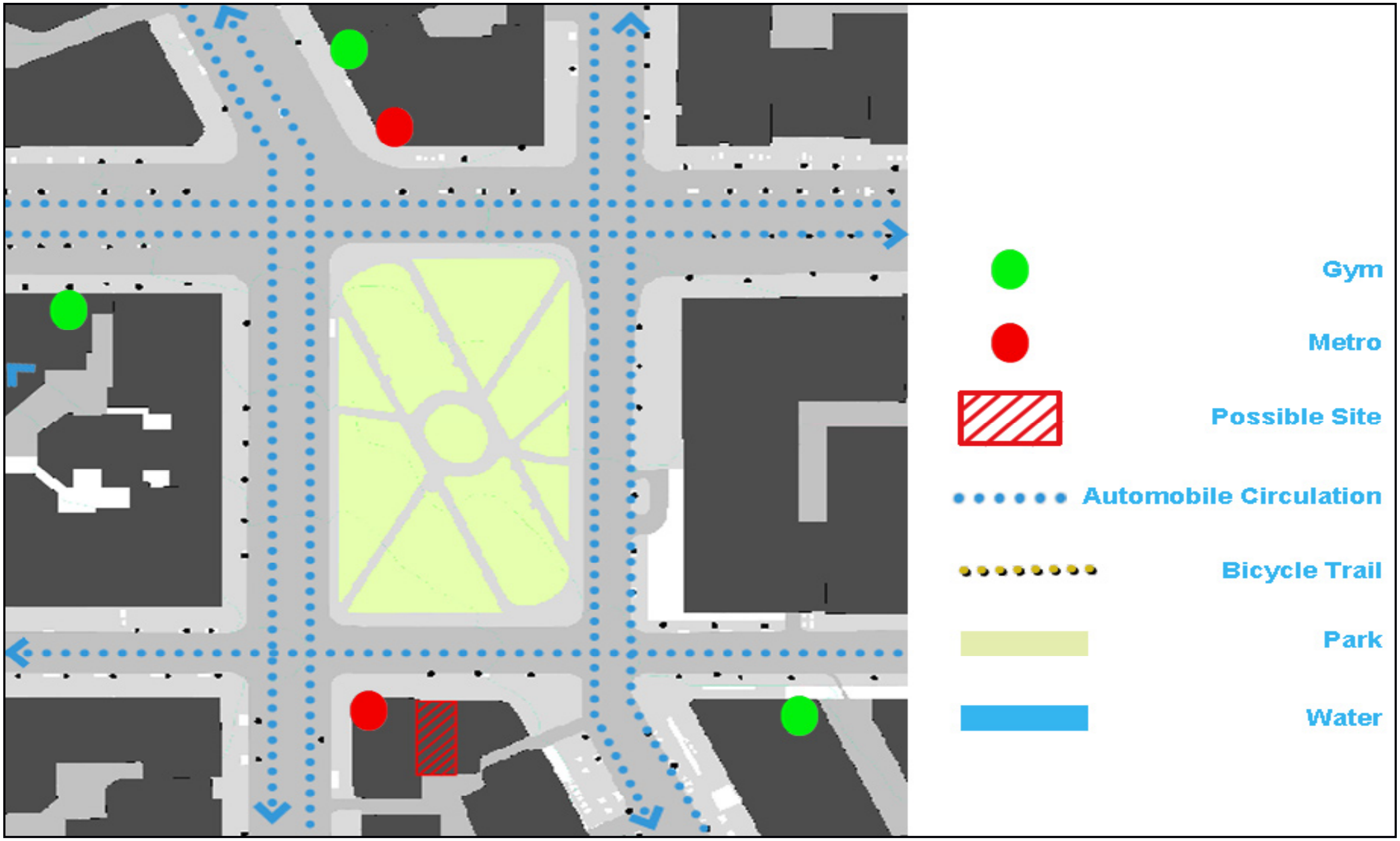


Figure 68. Farragut Square
The bicycle station is inserted into an existing building. Because of its proximity to several gyms, which have showers and changing facilities in them, the program will only need to address the parking.

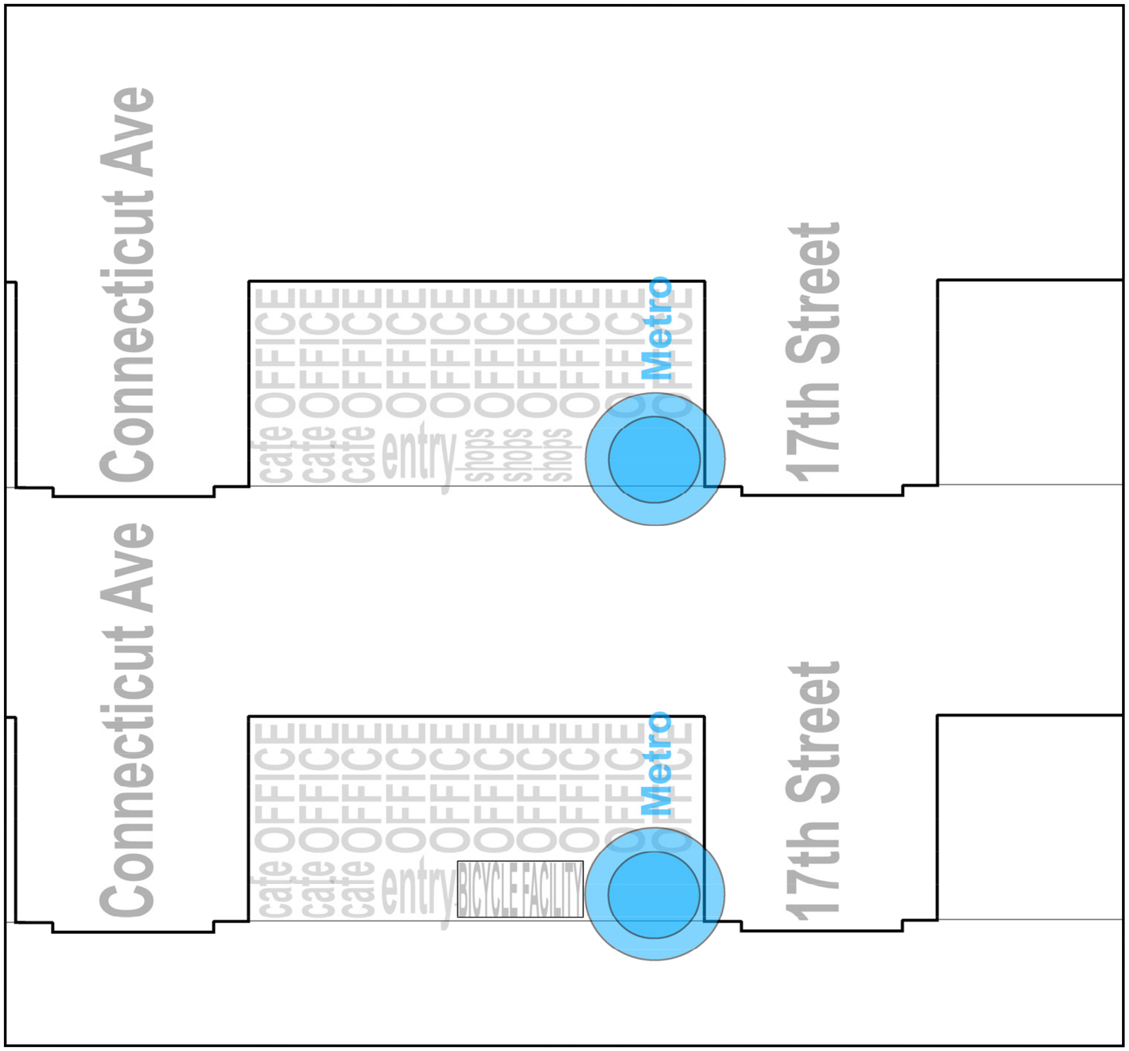


Figure 69. Farragut Square-Section
The bicycle station is inserted into an existing building. The Farragut West metro station and a cafe surround the bicycle station while offices are above the bicycle station.

Figure 70. Farragut Square-Photographs
The bicycle station is inserted into an existing building.

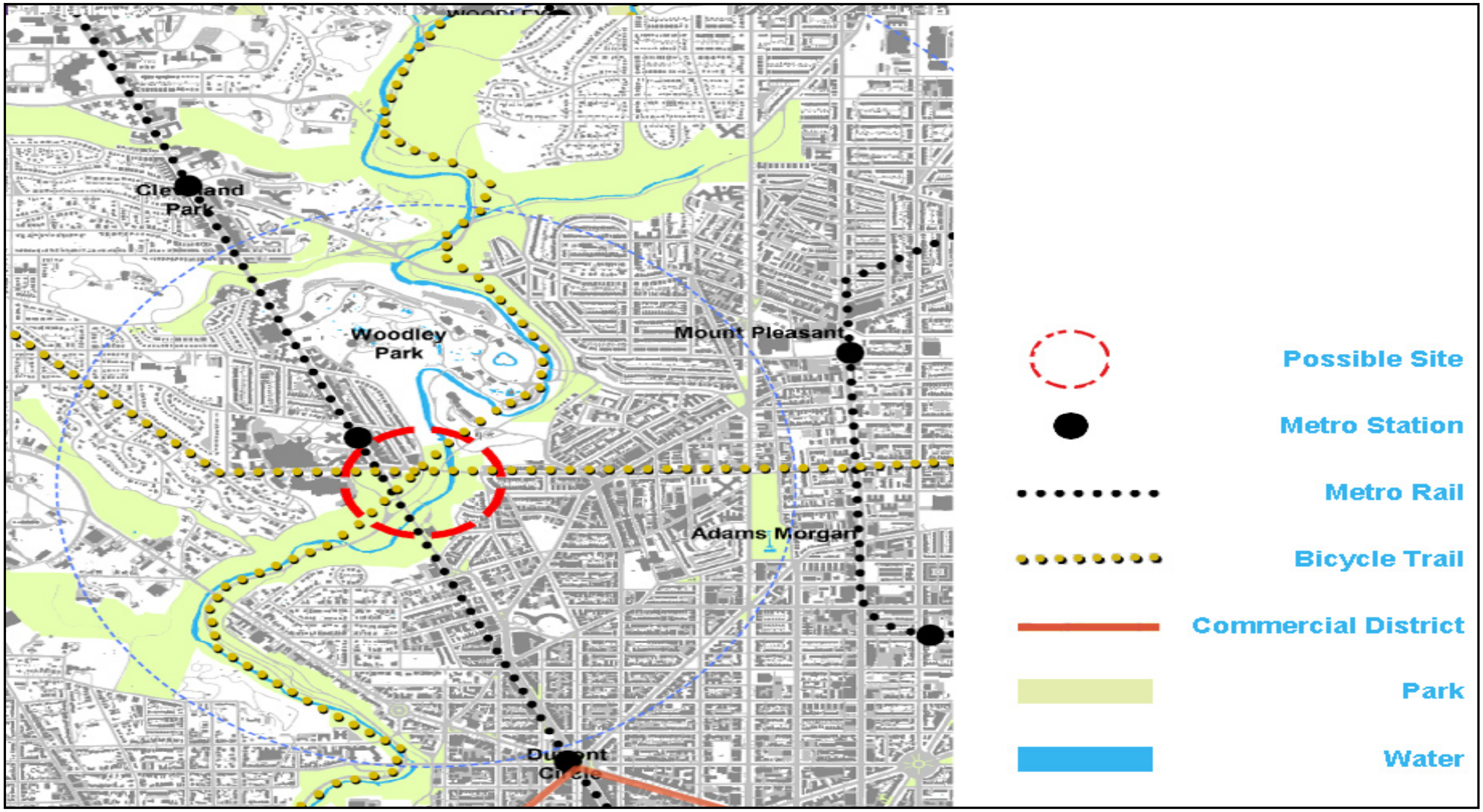


Figure 71. Woodley Park

Woodley Park is a community located on the western edge of Rock Creek Park just north of the commercial district. It is located where two trails intersect and is also serviced by one metro rail (red). This area has a large commuter population with very little bicycle parking available. Any bicycle parking near the metro station is usually taken which suggests a further need for parking. Because of the steep topography, this is also one of the last exits from Rock Creek Park that is navigable by bicycle.

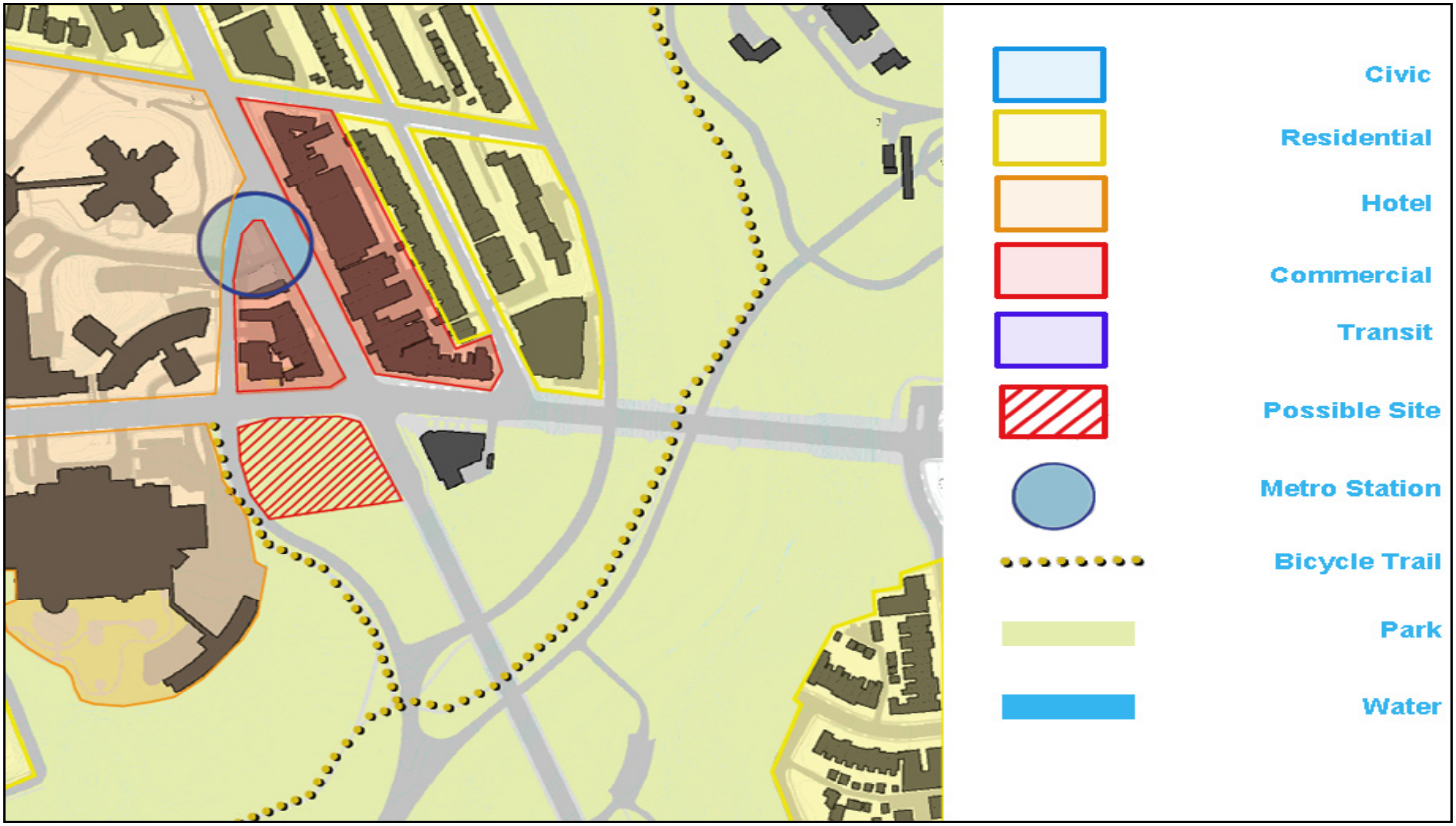


Figure 72. Woodley Park

Woodley Park is a community consisting of different uses. Along Connecticut Ave there is a small commercial district, which is where the metro station is. To the west of the commercial district are series of hotels. With the Rock Creek Park just south, these hotels offer the opportunity for bicycle rental to the visitors. To the north and east are residential buildings, whose residents would be the primary commuters to the bicycle station

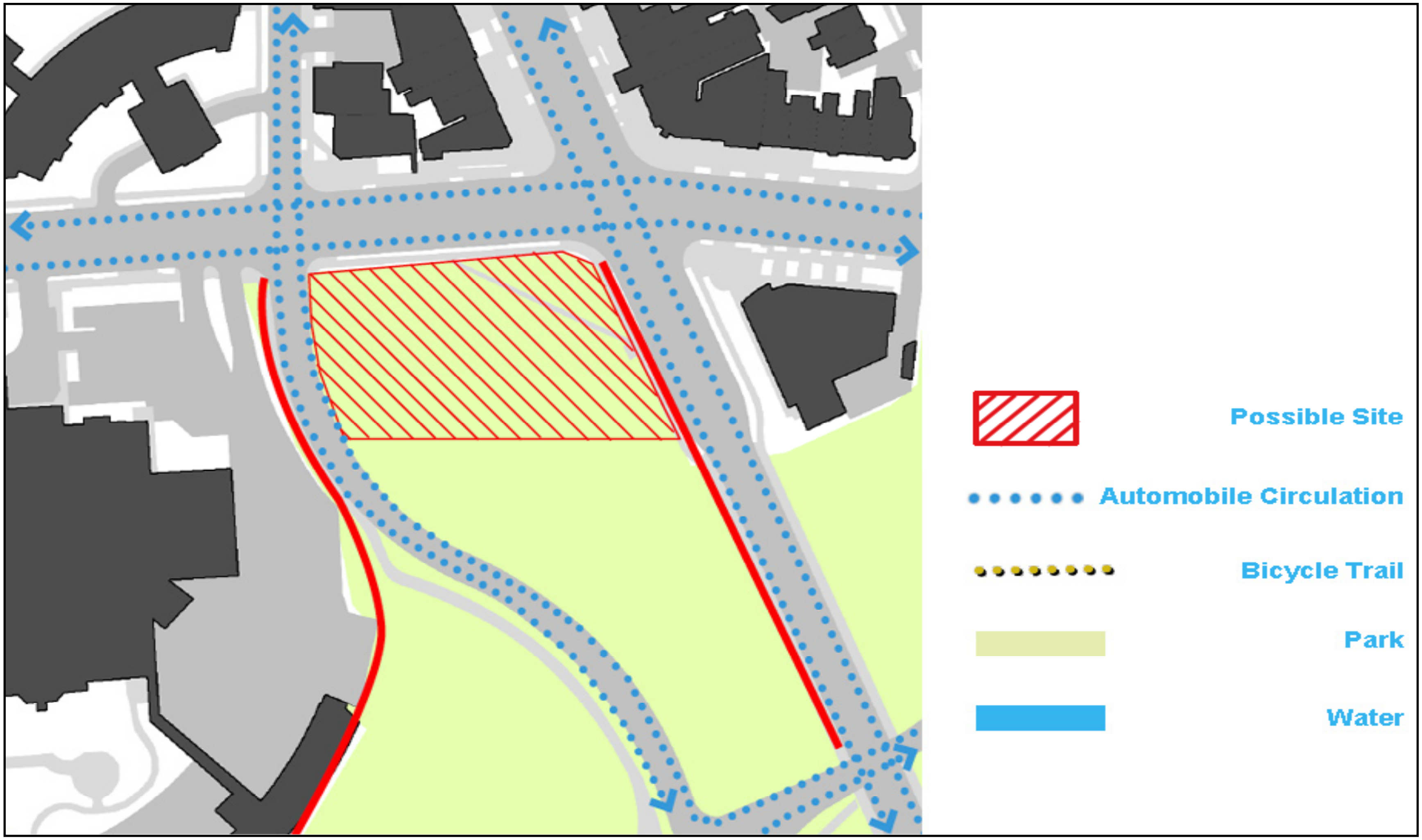


Figure 73. Woodley Park
The site for the bicycle station is located at the entrance of the Rock Creek Park. This is one block south of the metro station and would serve as a gateway to the park. Because the topography is steepest at this location, the building will help bicyclist mediate the grade change.

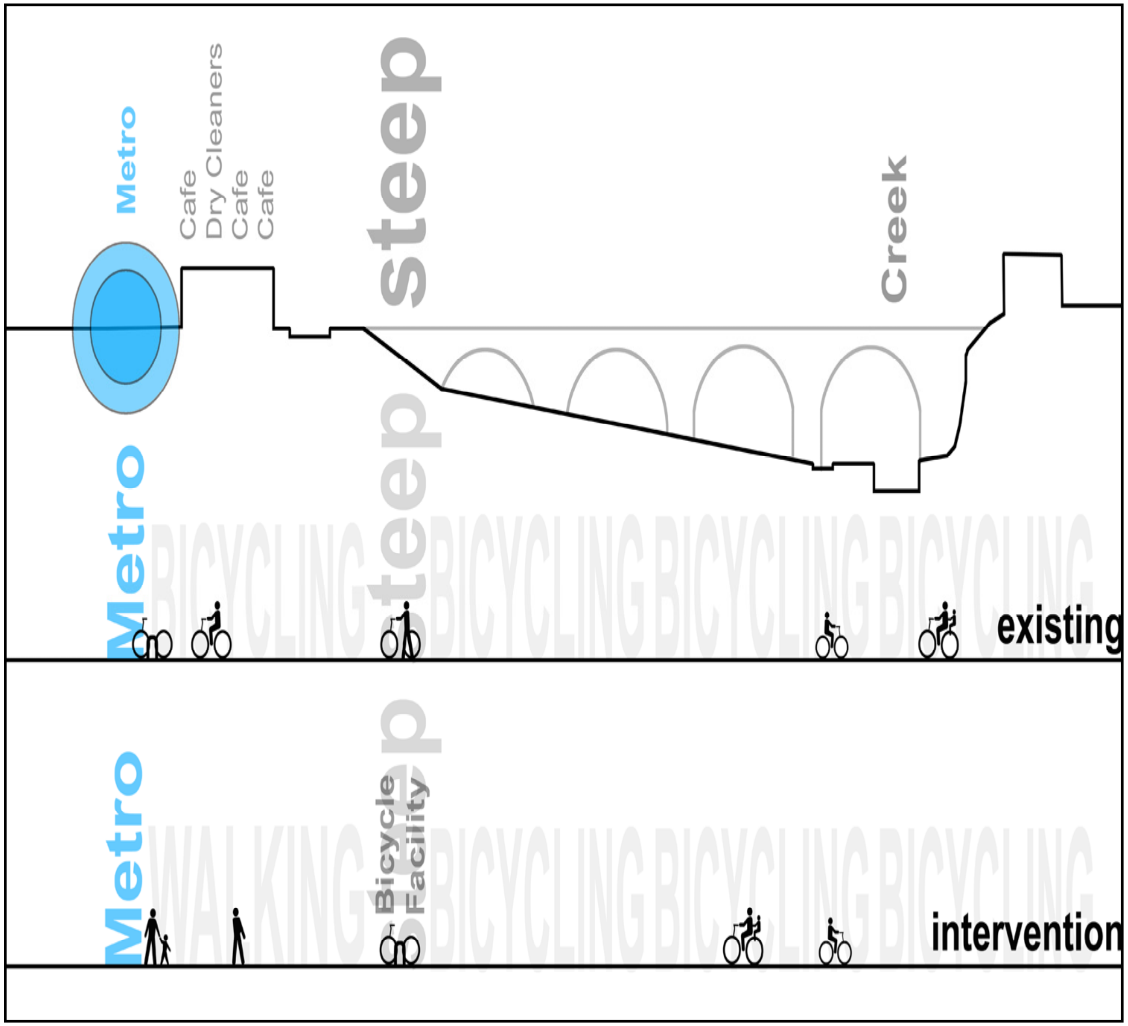


Figure 74. Woodley Park-Section

The site for the bicycle station is located at the entrance of the Rock Creek Park. This is one block south of the metro station and would serve as a gateway to the park. Because the topography is steepest at this location, the building will help bicyclist mediate the grade change.

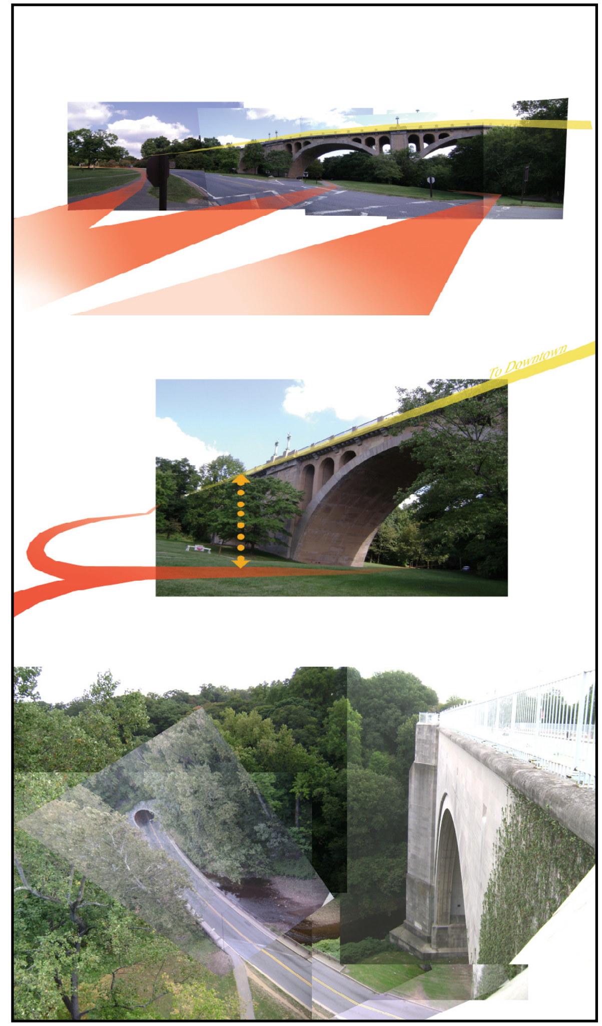


Figure 75. Woodley Park-Photographs

The bicycle station would be attached to the existing infrastructure and help bicyclists mediate the grade change.

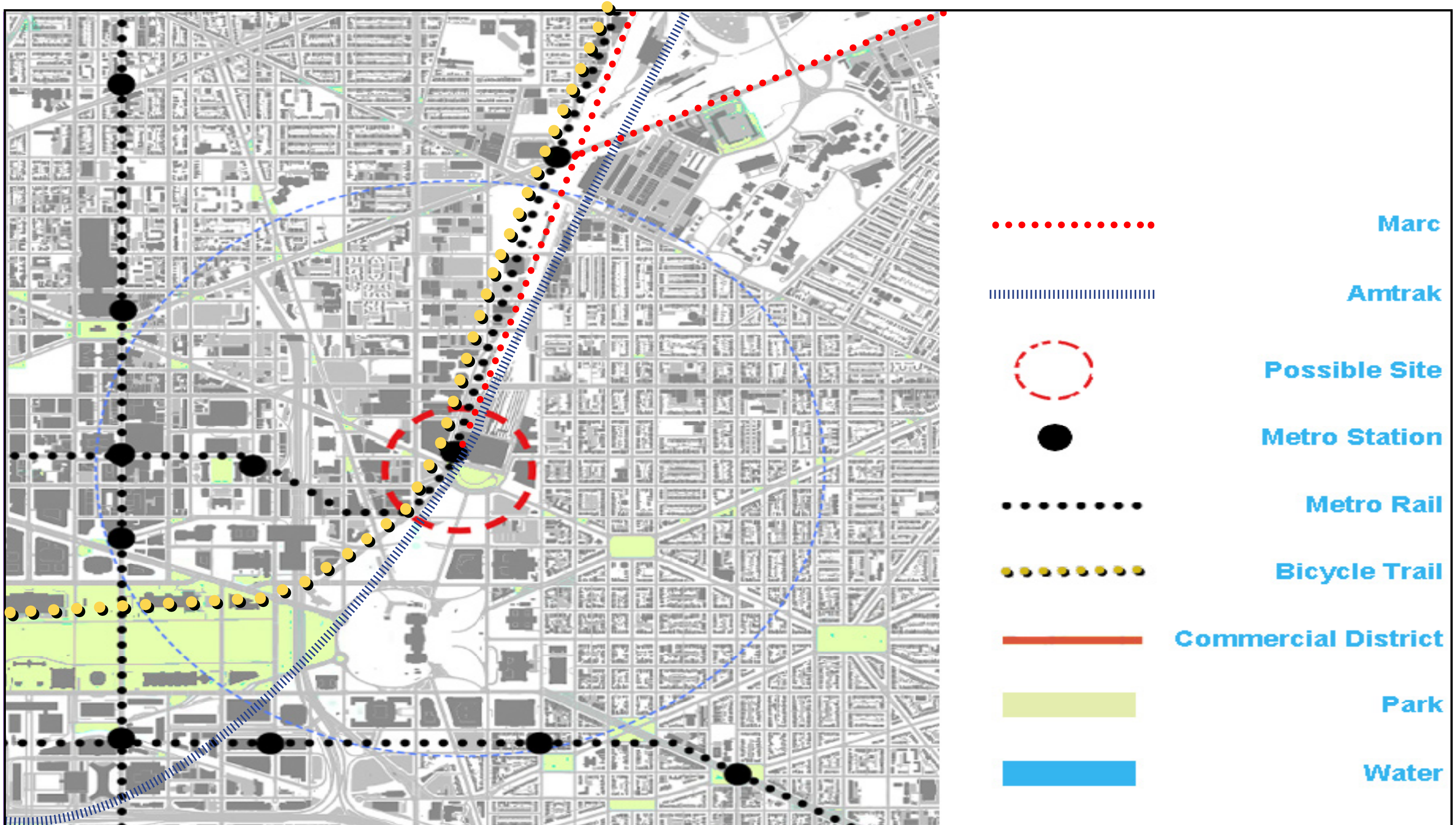


Figure 76. Union Station

Union Station is located just north of the US Capitol Building and the Mall and is located in the commercial district. It is the transit hub of Washington DC as it is serviced by one metro rail (red) and by Greyhound, Marc and Amtrak. It also sits adjacent to the Metropolitan trail, a trail that connects Maryland to Downtown Washington DC.

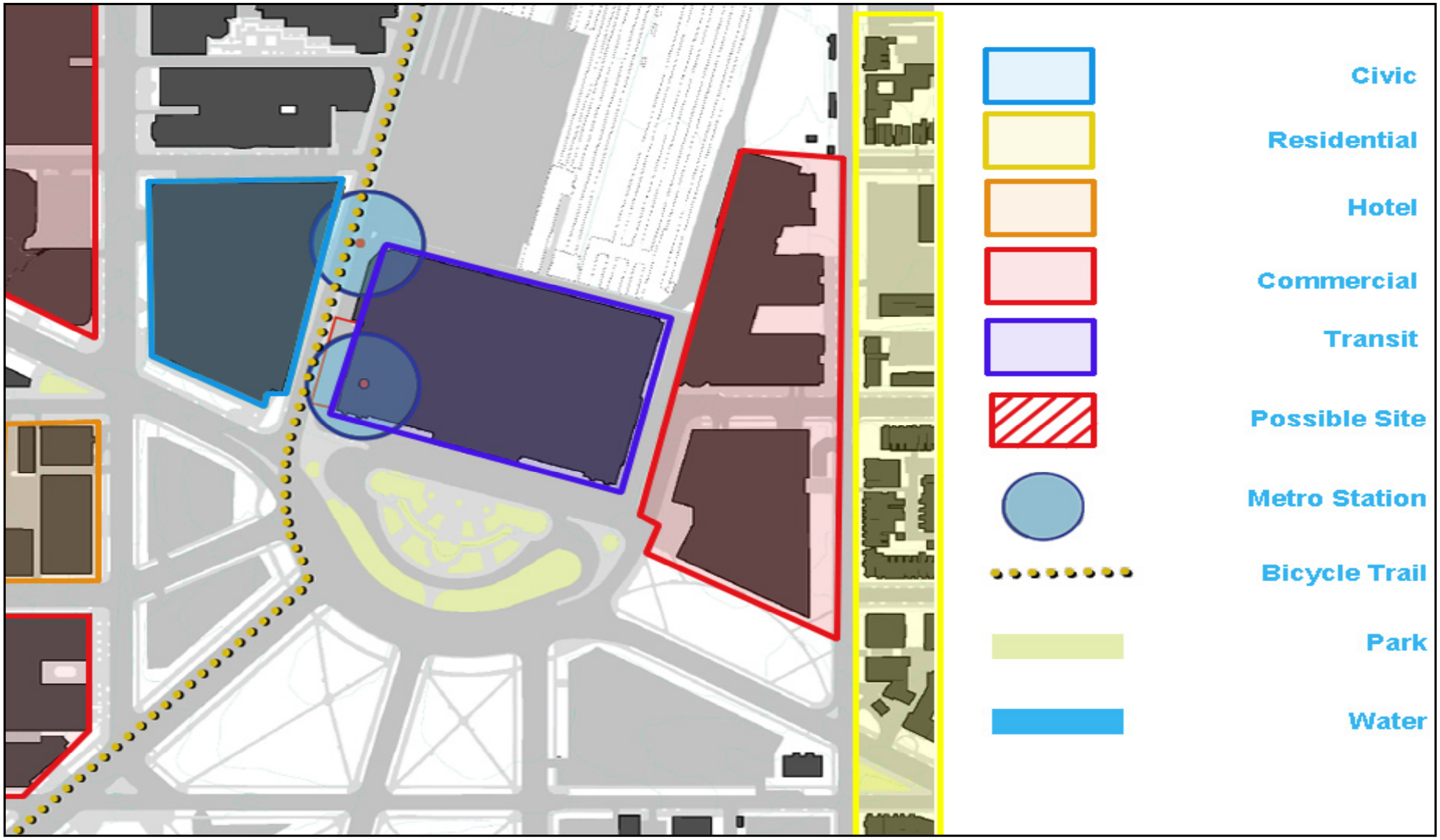


Figure 77. Union Station

Several metro entrances are located near Union Station. There are also several hotels, a residential neighborhood, and a major bicycle trail located in this area. Because of the surrounding use and proximity to the Mall, both a rental and storage facility to be feasible in this area.

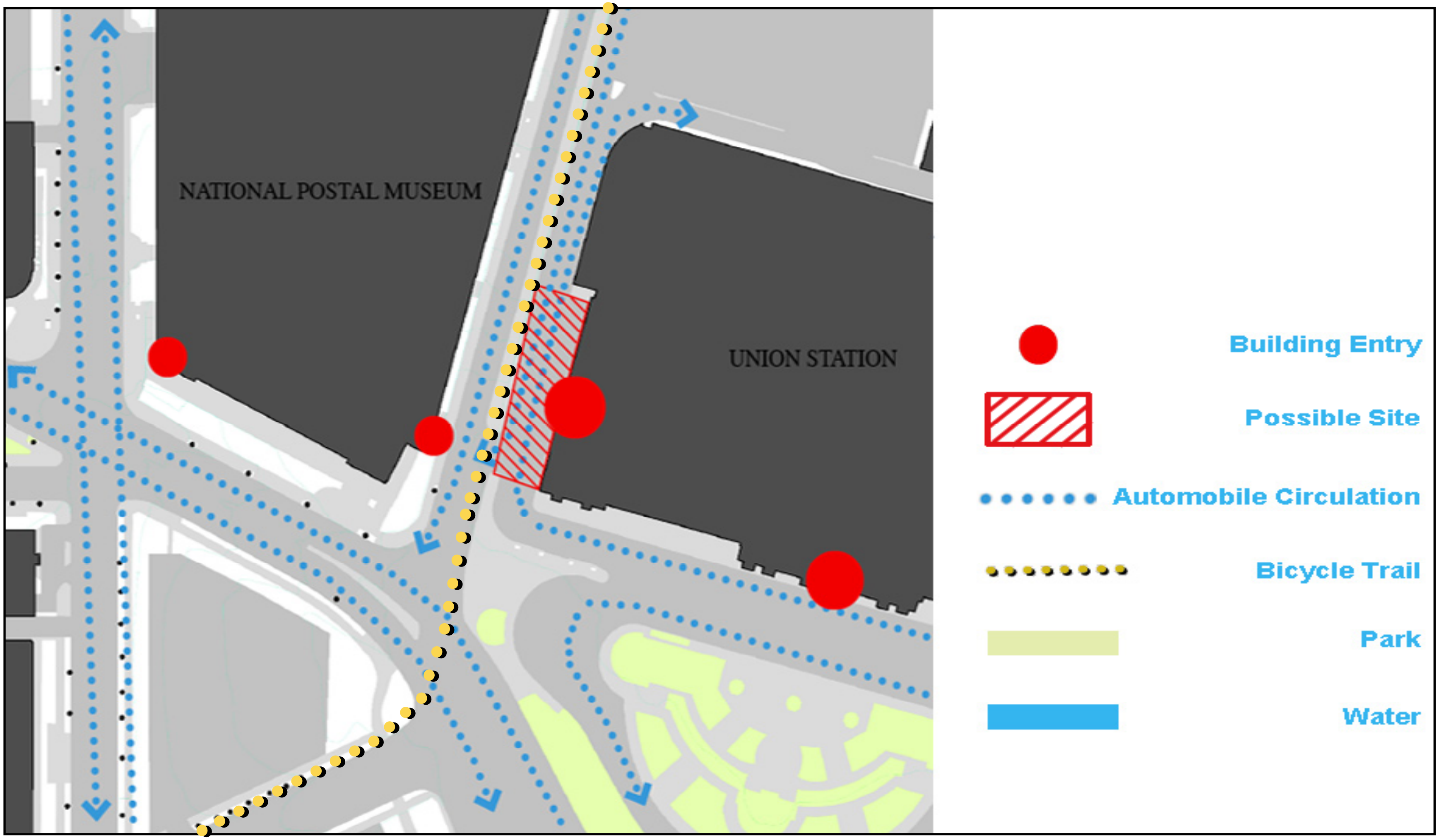


Figure 78. Union Station
The site for the bicycle station is located between the western entrance of Union Station and the eastern entrance to the National Postal Museum on 1st Street. Currently the site serves as an entrance and exit for the parking garage behind Union Station. The entrance to the metro also occurs at this site.

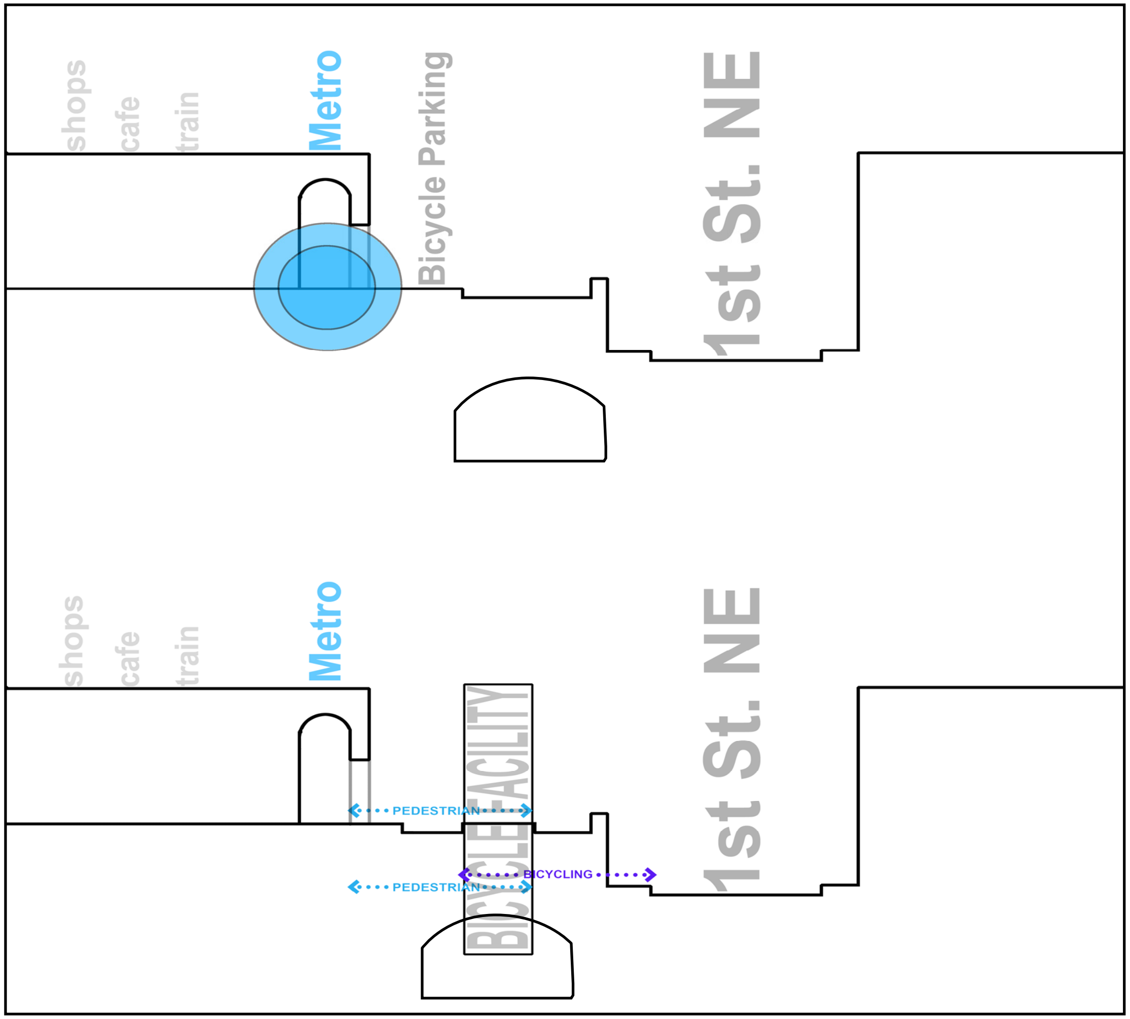


Figure 79. Union Station-Section
The site for the bicycle station is located between the western entrance of Union Station and the eastern entrance to the National Postal Museum on 1st Street. The entrance to the metro occurs at this site. The bicycle station will connect 1st Street, the metro Station, and Union Station.

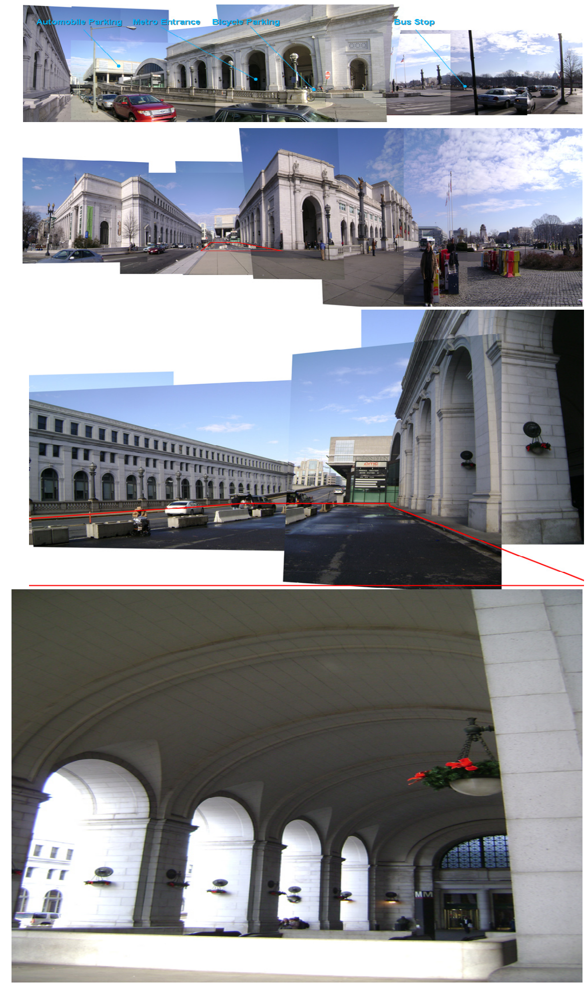


Figure 80. Union Station-Photographs
The bicycle station is located adjacent to Union Station. The entrance to Union Station consists of large classical style vaults and the facade of the National Postal Museum is classical as well.

Design Approach

This thesis investigates techniques of digital design, fabrication, and assembly through the exploration of carbon fiber. It proposes a design process that merges the idea of the architect as a master builder with current digital technology. The result is a parametric design process, which uses not only an understanding of site and program conditions, but also an understanding of materiality and the implications of it on fabrication and assembly for design.

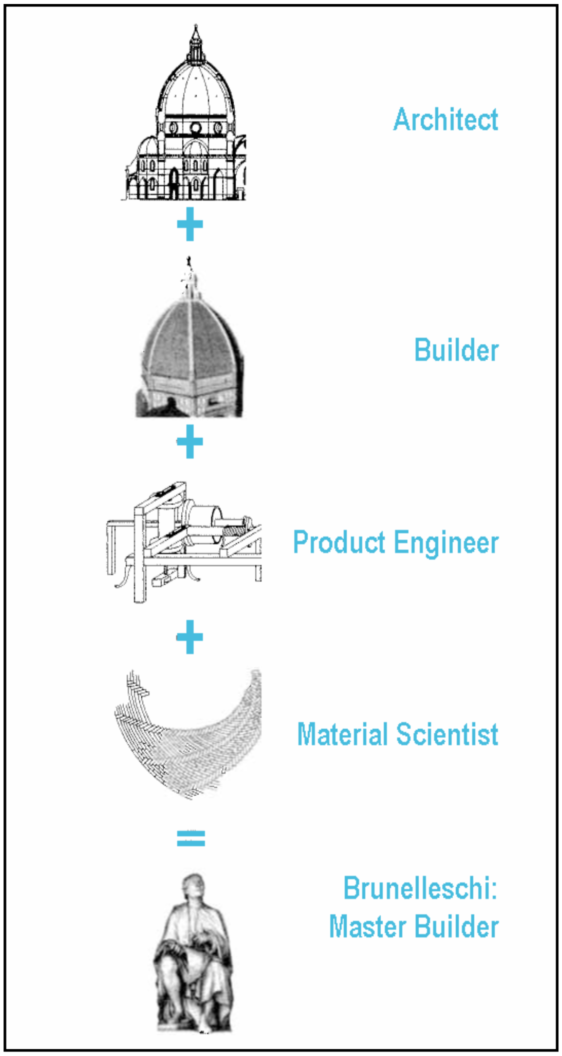


Figure 81. Architect as Master Builder
Historically the architect had an understanding in various disciplines. With the implementation of new technology, the architect's role has been narrowed.
[Refabricating Architecture 26]

Parametric design is a design process in which the designer can create an infinite number of design possibilities through the assignment of a series of variables with specific values. In parametric design, it is the parameter that is defined, not the shape. By assigning different values to the parameter, different solutions can be created. This thesis looks at three parametric inputs- program, material and site. By using a parametric design process, multiple designs can be generated based on changing site conditions while maintaining the parameters of the program and material.

This process is tested on two sites. The Farragut Square Bicycle Station tests how a bicycle station can be inserted into an existing building. This insertion explores prefabricated carbon fiber surface and how it can be inserted into existing architecture. It uses site, programmatic, materiality, and structural constraints to influence the design of the bicycle station.

The process is also tested on a bicycle storage facility located at Union Station. Union Station is the transportation node serving as a connection point of the Metro, MARC, and Amtrak. This facility explores both small-scale and large-scale applications of carbon fiber surface which is influenced by site, programmatic, environmental, materiality, and structural constraints.

site-explore how site conditions influence form. Site is explored through natural environmental conditions and built conditions. Natu ral conditions include temperature, sunlight, rain, wind, snow, seismic, and topography. Built conditions include context, use, circulation, in frastructure, building and transit rules.

program -explore how programmatic conditions influence form. Pro grammatic conditions includes how surrounding buildings program matic use impact the form. Program can be influenced by a number of factors including human movement and form.

material -explore how material can influence form. Material is ex plored through an analysis of its formability, structural properties, ease of fabrication and assembly, permeability, and sustainabilty.

Figure 82. Design Constraints
This thesis proposes a parametric design process in which the constraints for the design come from site conditions, program conditions, and material conditions. As each condition is applied, a matrix of solutions is created. This process allows several versions of a design to be explored by changing the parameters of the condition.

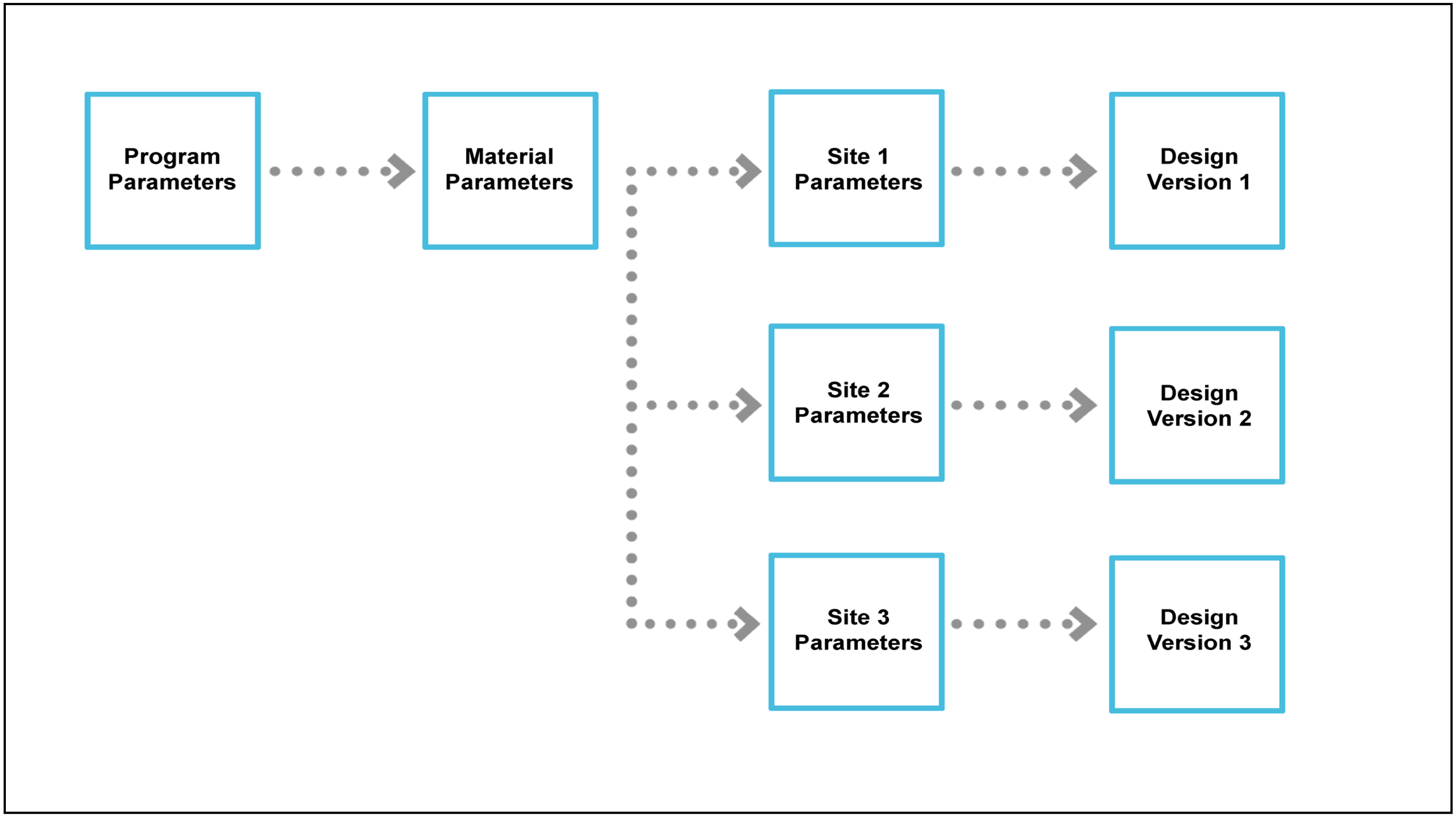


Figure 83. Design Process Flow Diagram
This thesis explores how carbon fiber (material) can be applied to the creation of a bicycle station on several urban sites. This diagram shows this process in which the program and material parameters are kept constant and the site parameters of the site are allowed to change. The result of this design process is several versions of a bicycle station based on changing site conditions.

Site-**explore how site conditions influence form.**

Program-**explore how form and surface can be influenced by program.**

Material-**explore how material selection can influence form and surface.**

Structure-**explore how structural systems influence form and structure.**

Figure 84. Farragut Square Bicycle Station Design Constraints
The design for the Farragut Square Bicycle Station explores using prefabricated carbon fiber surface panel. The design process includes the following constraints: Site Program Material Structure. Site is the first constraint that is applied to the design. This includes edge and infrastructure constraints and explores how these conditions affect surface. Program is then applied to the design. The surface reacts to the programmatic constraints creating varying forms. Material is then applied to the surface. The material has certain structural and formal properties that affect the form and surface. Finally structure is applied to the material surface. The surface changes based on structural constraints.

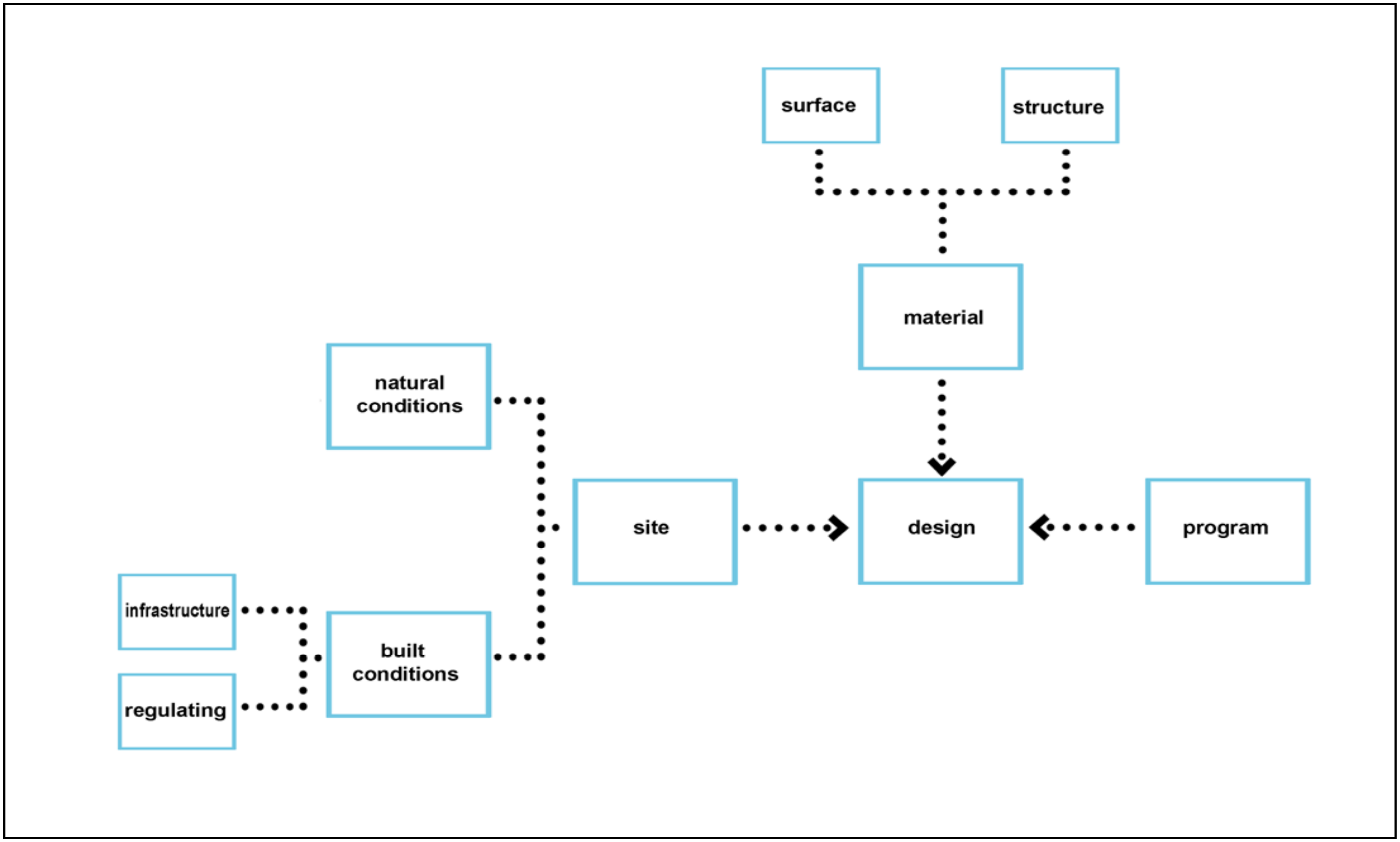


Figure 85. Farragut Square Bicycle Station Design Process Flow Diagram
The design process includes the following constraints: Site Program Material Structure. This diagram shows the various inputs for the design of the Farragut Square Bicycle Station.

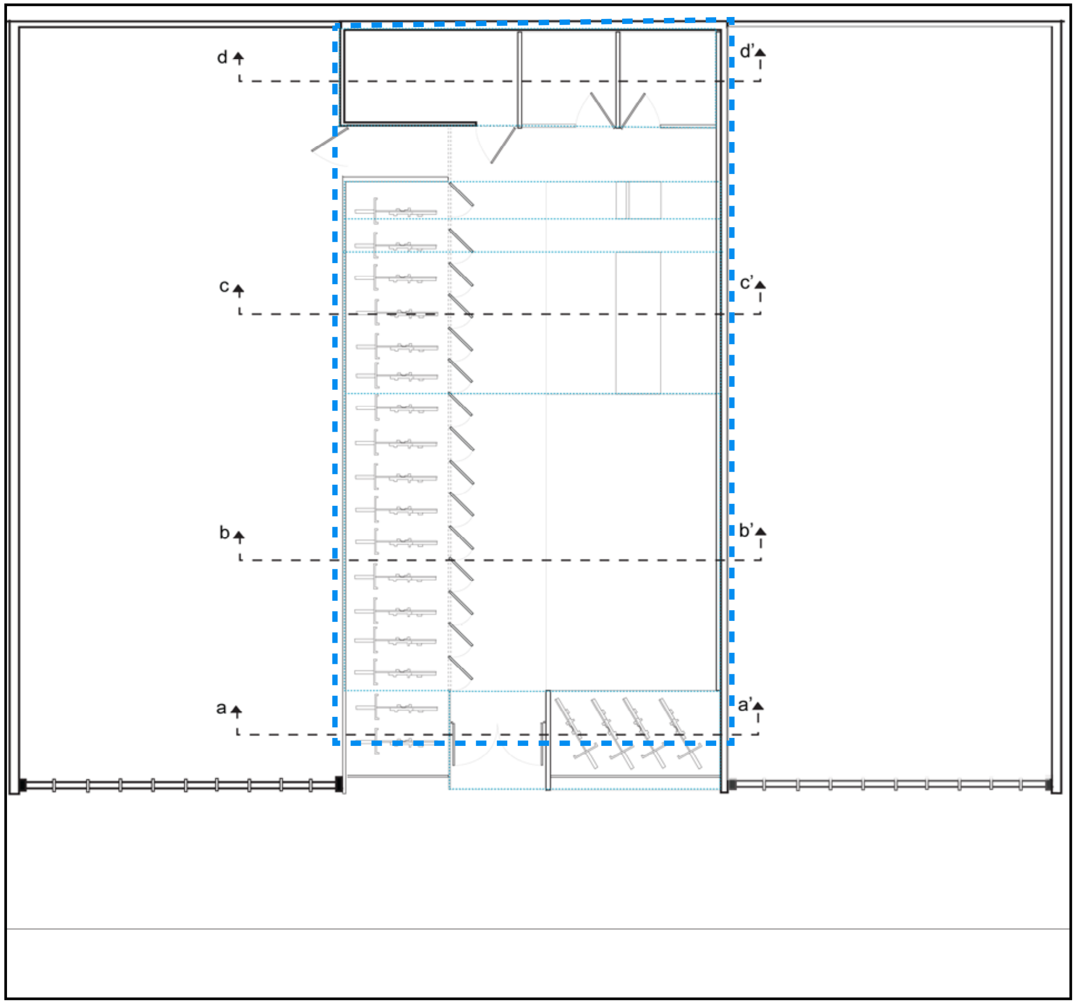


Figure 86. Farragut Square Bicycle Station Plan (Site)
The first constraint for the design of the bicycle station is defined by the site. The edges of the bicycle station are defined because it is inserted into an existing building. The surface must conform to these edges. The surface must also conform to existing infrastructure such as HVAC and structure.

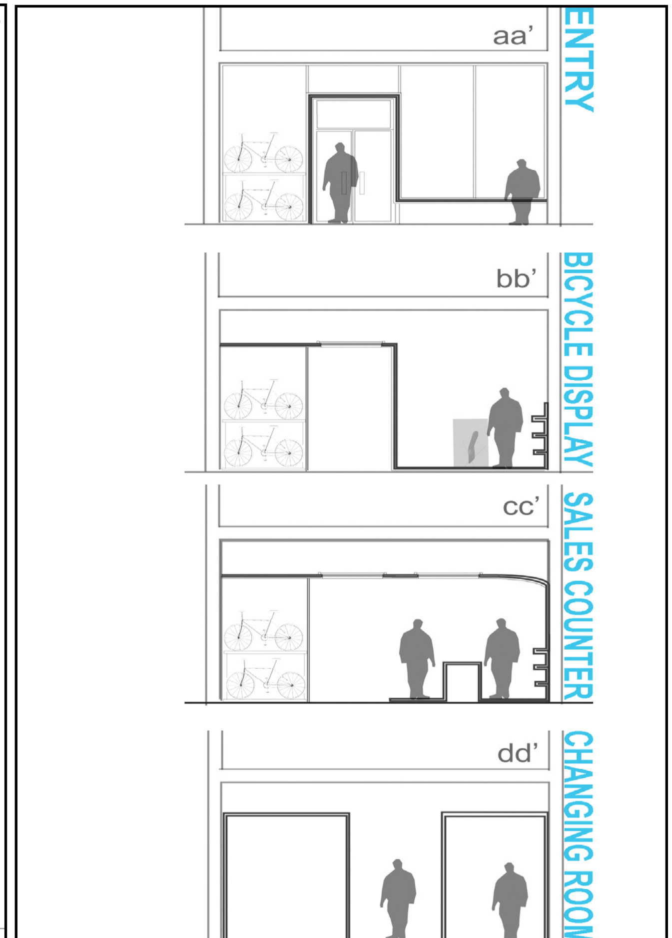


Figure 87. Section (Program)
The surface takes its form by reacting to programmatic constraints. On the facade the surface creates a threshold for entering the building while also acting as a seating area for people on the street. The walls fold to create shelves for displaying while the floor folds to create a counter and seat.

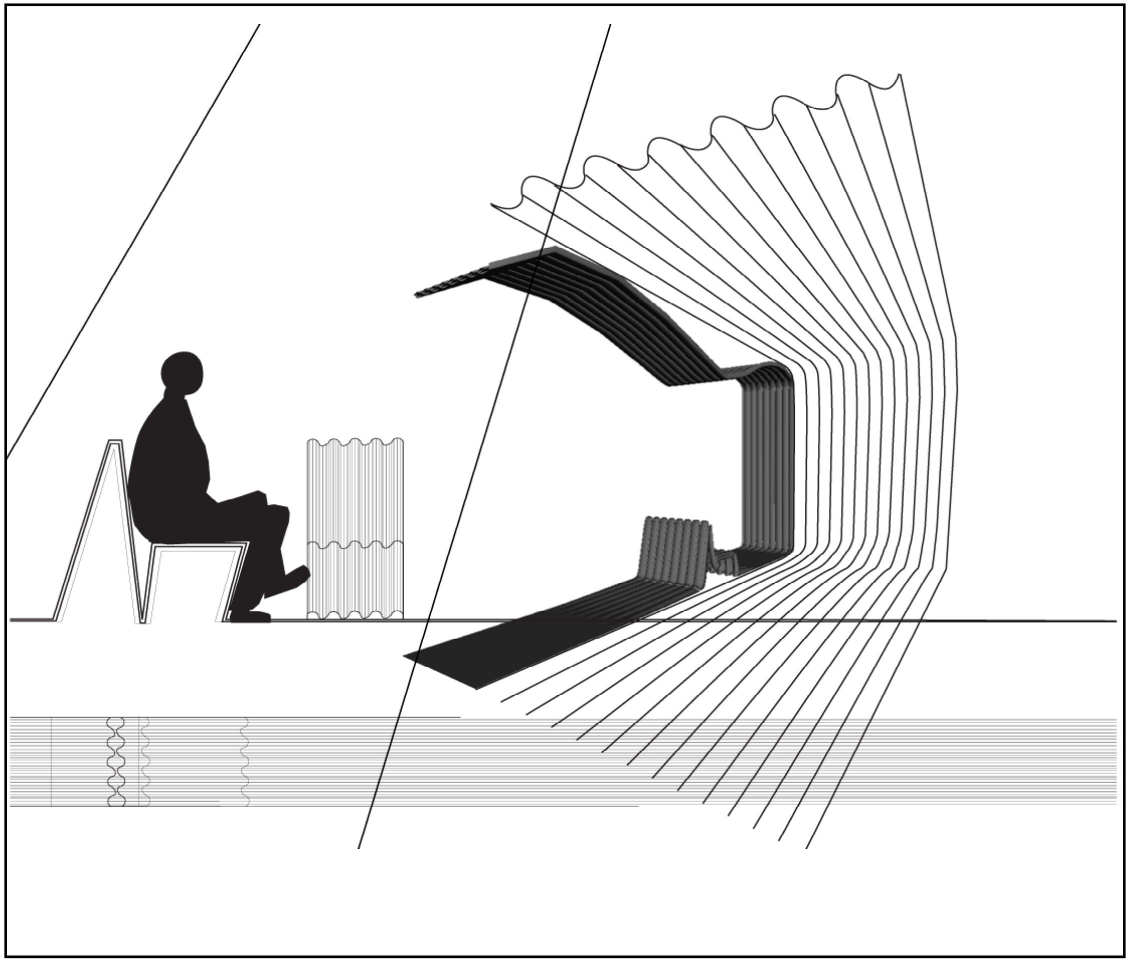


Figure 88. Seating and Wall Conditions (Site, Program, Material and Structure)
After the surface takes its form, the properties of carbon fiber are applied. Carbon fiber allows the surface to be extremely thin yet incredibly strong. Carbon fiber's ability to take virtually any shape including structural forms eliminate the need for additional structure. In this case the corrugation allows the surface to span without additional support. The result is a self-supporting prefabricated carbon fiber surface

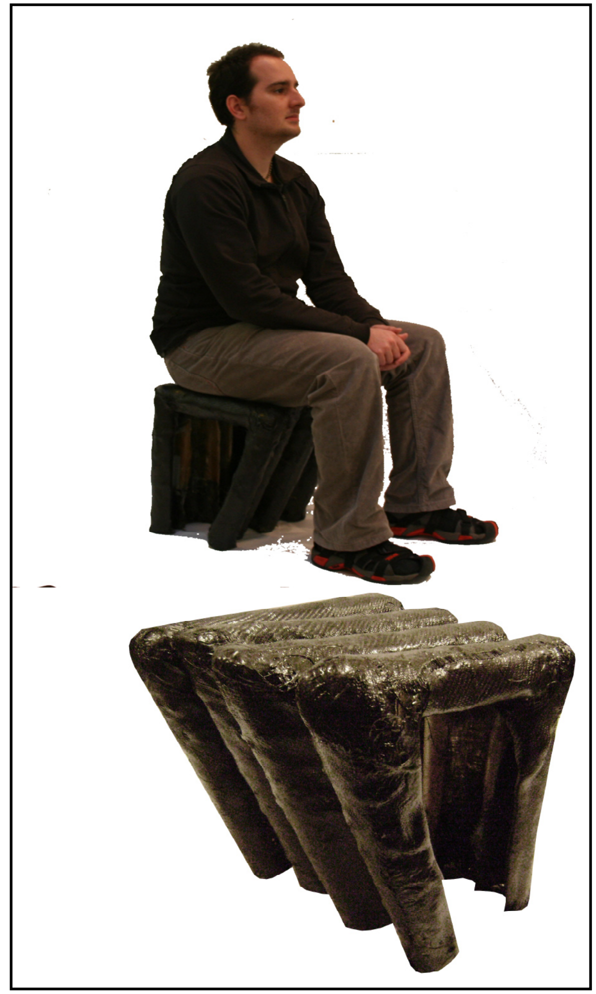


Figure 89. Seating (Material and Structure)
The bench takes its form from both the program and the structural requirements. The seat is made of carbon fiber and has a corrugated form which allows the surface to be extremely thin.

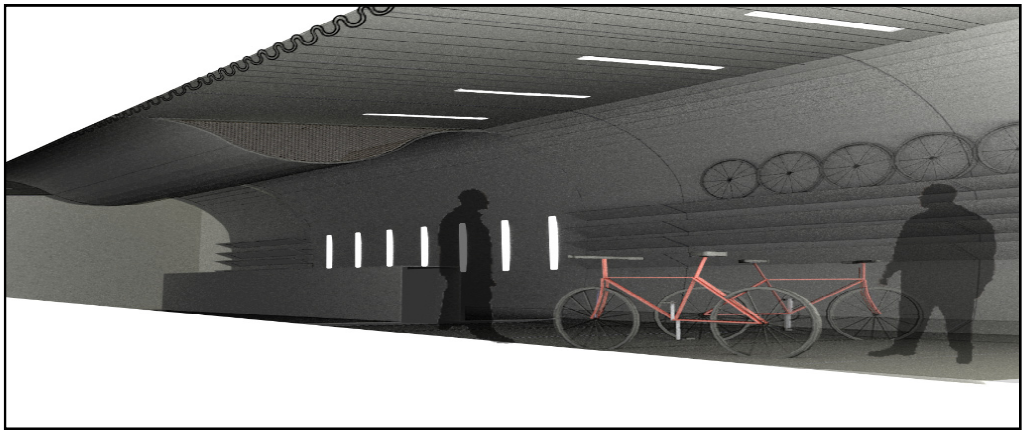


Figure 90. Display Area of the Bicycle Station (Site, Program, Material and Structure)
View of the bicycle display area and the sales counter. The wall folds in and out to allow shelving for bicycle parks. The sales counter is the result of the floor surface folding. The ceiling folds around the HVAC.

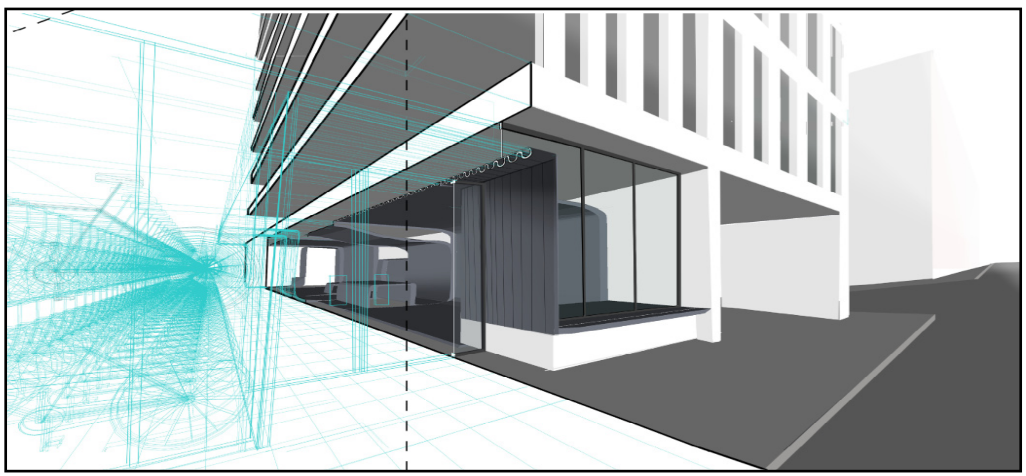


Figure 91. Entry of the Bicycle Station (Site, Program, Material and Structure)
View of the entry of the bicycle station. Shows the carbon fiber surface and how it reacts to programmatic conditions. The surface is corrugated so it is structural.

Figure 92. Corrugated Carbon Fiber Surface (Material and Structure)
Physical version of carbon fiber wall surface with corrugation.

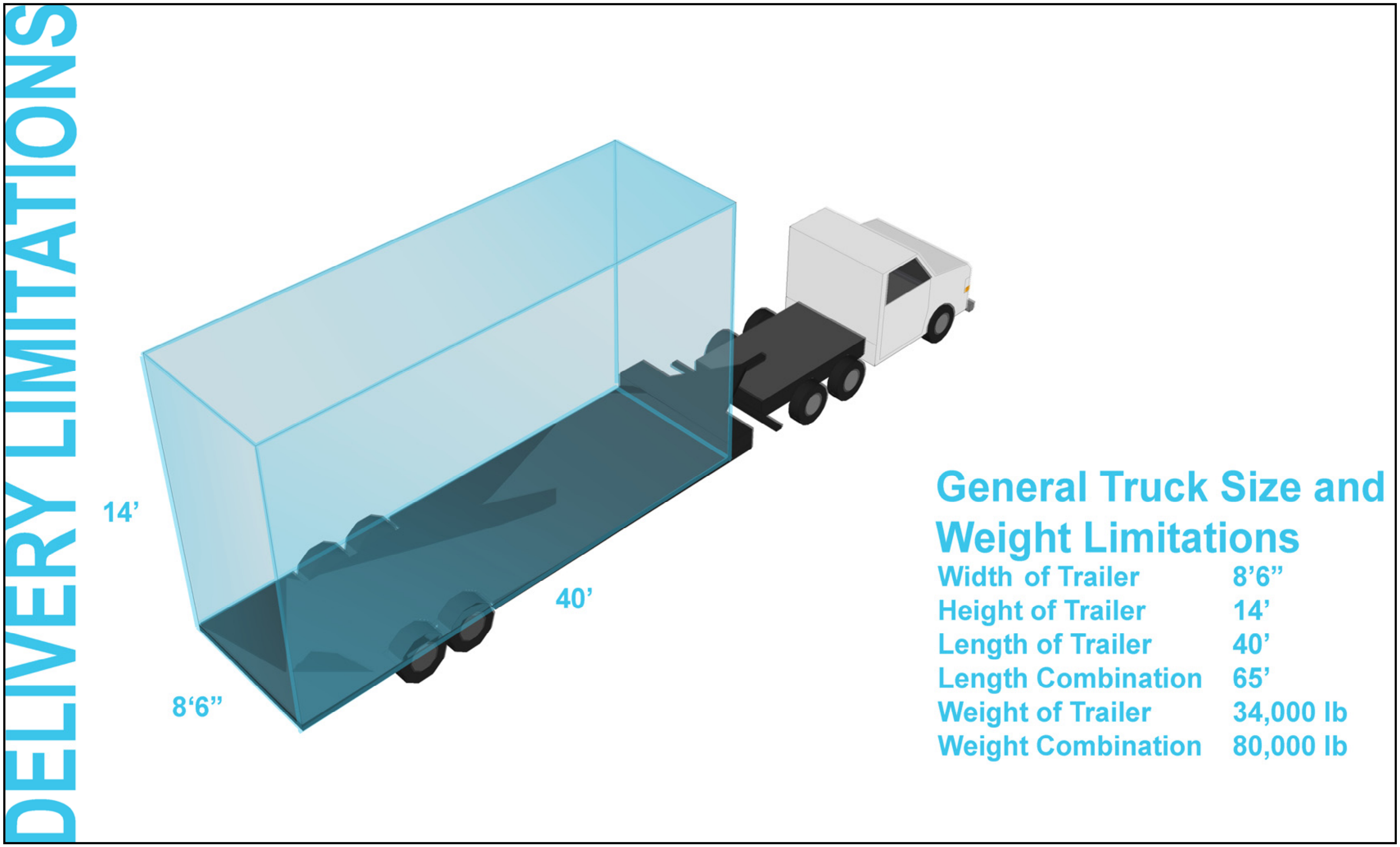


Figure 93. Prefabricated Surface Delivery Limitations

The size of the prefabricated surface is constrained by the size permitted by the truck delivering the surface. Generally the size of the component delivered must not be taller than 14’, wider than 8’6”, and longer than 40’.

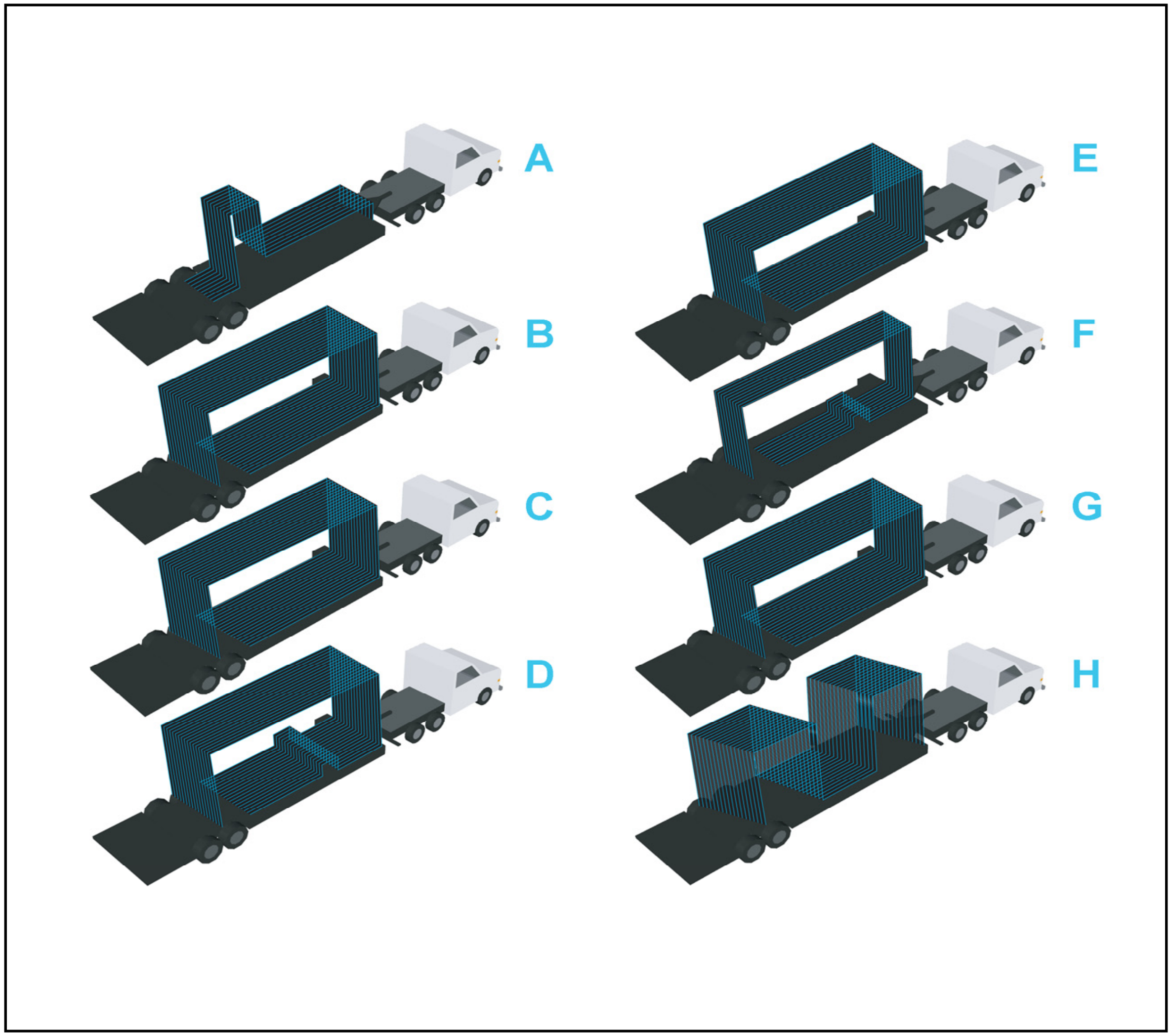


Figure 94. Delivered Prefabricated Surface
The size of the prefabricated surface is constrained by the size permitted by the truck delivering the surface. The individual prefabricated surfaces are delivered and inserted in the building.

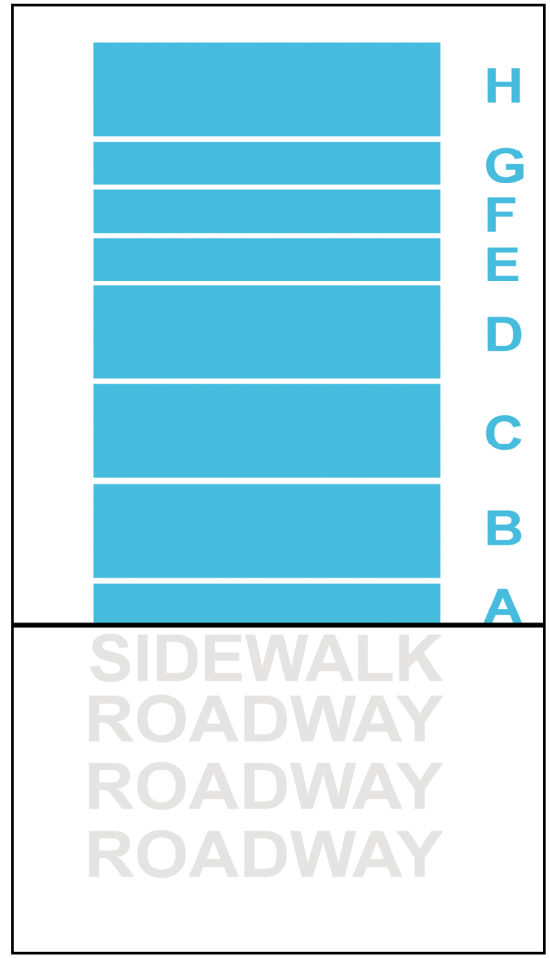


Figure 95. Assembly Order of the Prefabricated Surface
Each surface is inserted in the building in order. They are slid into the building through the storefront and attached to the existing infrastructure.

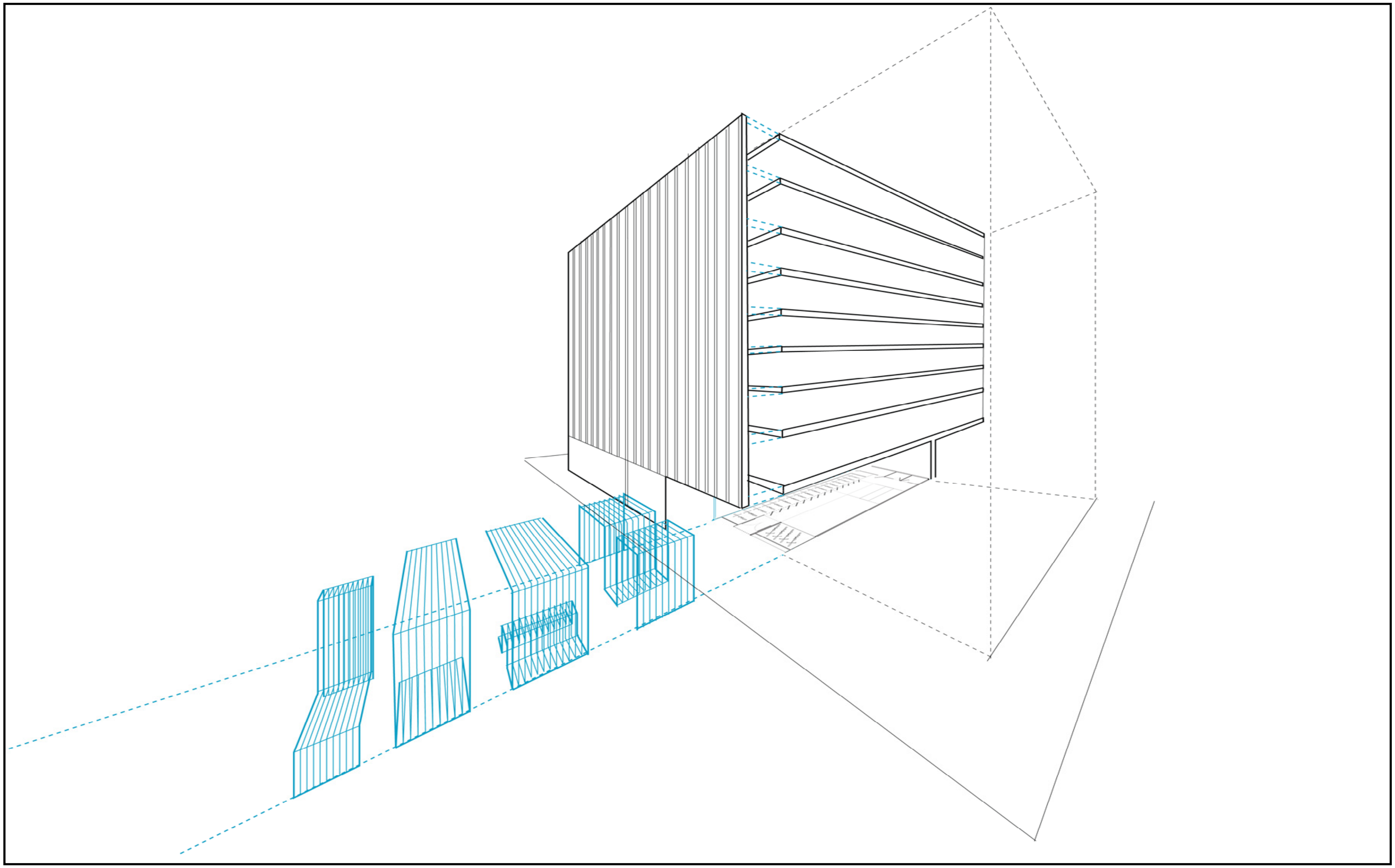


Figure 96. Delivered Prefabricated Surface Inserted into the Building
The individual prefabricated surfaces are delivered and inserted in the building.

Site-**explore how site conditions influence form. These include edge conditions, traffic conditions, form, and existing infrastructure.**

Program-**explore how form and surface can be influenced by program.**

Sunlight-**explore how the form, surface, and color can be used to naturally light the interior of the building by bouncing visible light onto the ceilings and reflecting it deep into the interior.**

Solar Gain-**explore how form, surface, and color can be used to prevent solar gain in the summer will allowing solar gain in the winter.**

Rain Water-**explore how form and surface can be used to direct water to the periphery of the building.**

Material-**explore how material selection can influence form and surface.**

Structure-**explore how structural systems influence form and structure.**

Figure 97. Union Station Bicycle Station Design Constraints

The design for the Union Station Bicycle Station explores using prefabricated carbon fiber surface panels. The design process includes the following constraints: Site Program Material Structure. Site is the first constraint that is applied to the design. This includes the edge condition created by the existing buildings, traffic, and infrastructure and explores how these conditions affect surface. Program is then applied to the design. The surface reacts to the programmatic constraints creating varying forms. Environmental constraints including sunlight and rainwater are applied to the surface. Material is then applied to the surface, which has certain structural and formal properties that affect the form and surface. Finally structure is applied to the material surface. The surface changes based on structural constraints.

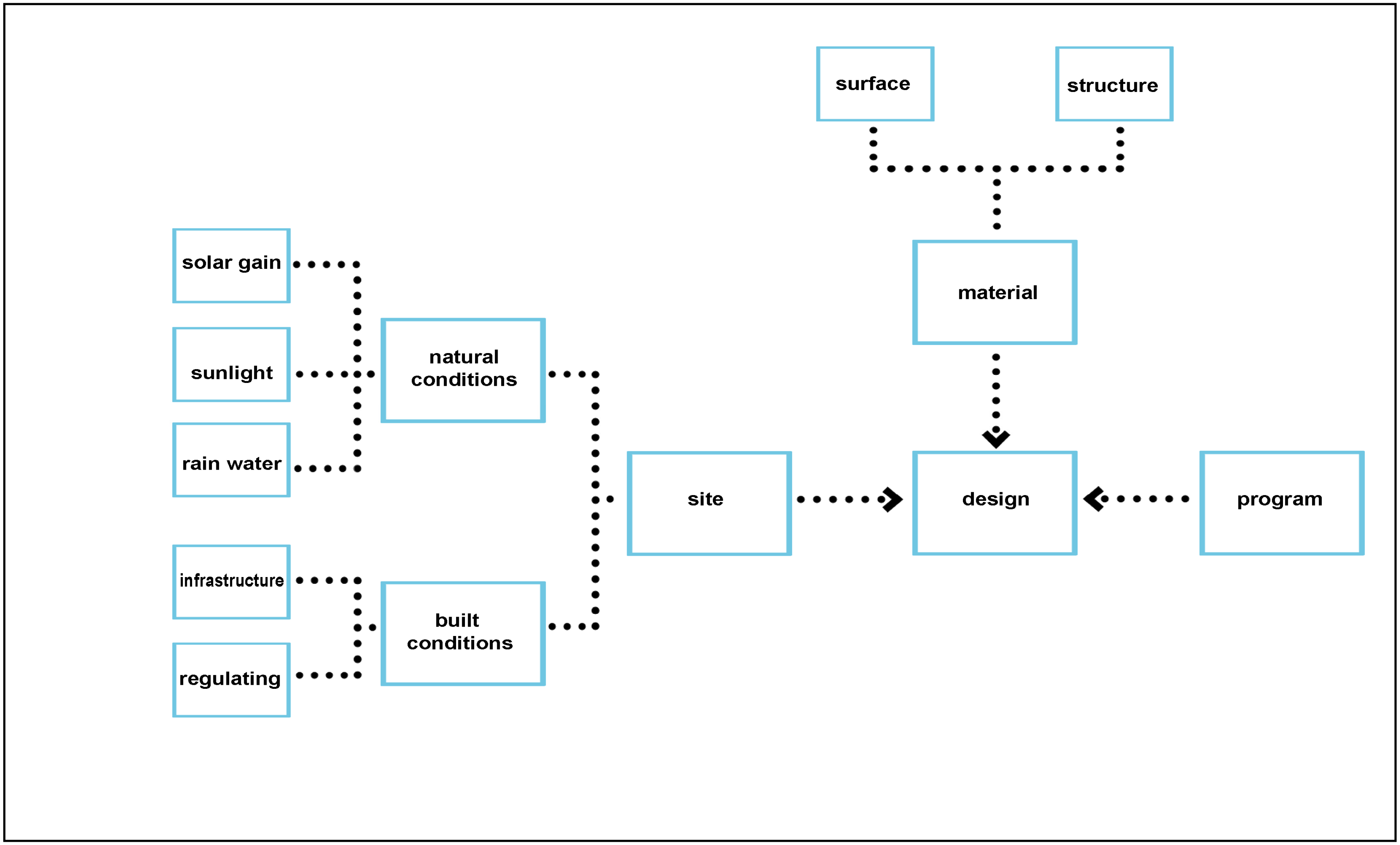


Figure 98. Union Station Bicycle Station Design Process Flow Diagram
The design process includes the following constraints: Site Program Material Structure. This diagram shows the various inputs for the design of the Union Station Bicycle Station.

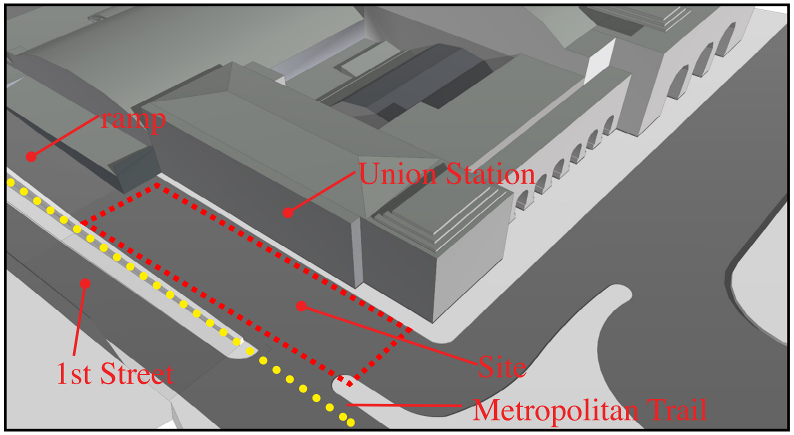


Figure 99. Union Station Bicycle Station Potential Site Location (Site)
The site for the Union Station Bicycle Station is located along the Metropolitan Trail on the western side of Union Station on the parking garage ramp.

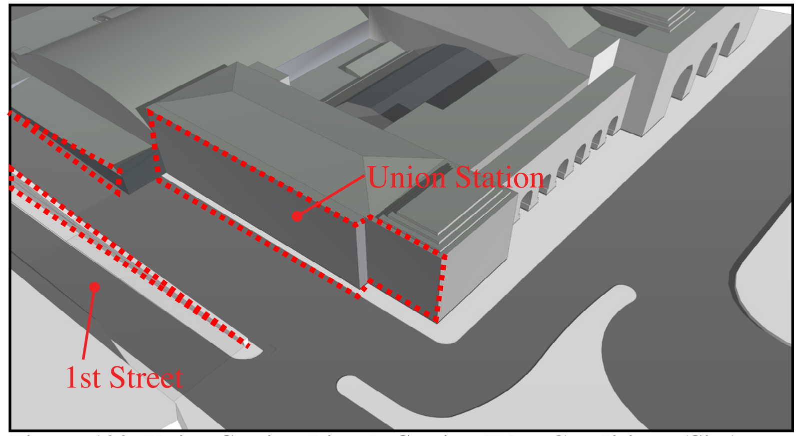


Figure 100. Union Station Bicycle Station Edge Conditions (Site)
The site for the Union Station Bicycle Station is located on the western side of Union Station between the entry vestibule to Union Station and 1st street. 1st Street slopes down and the parking garage slopes up.

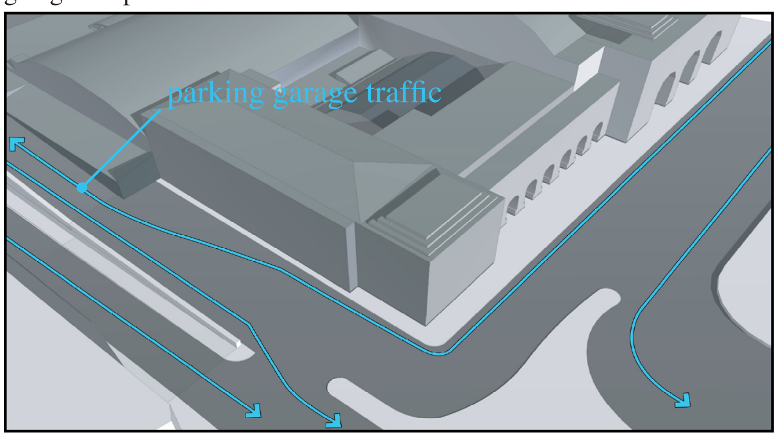


Figure 101. Union Station Bicycle Station Vehicular Traffic (Site)
The site for the Union Station Bicycle Station is located on the existing ramp to Union Station's parking garage. The ramp has two way traffic. Traffic entering the garage originates from the front of Union Station.

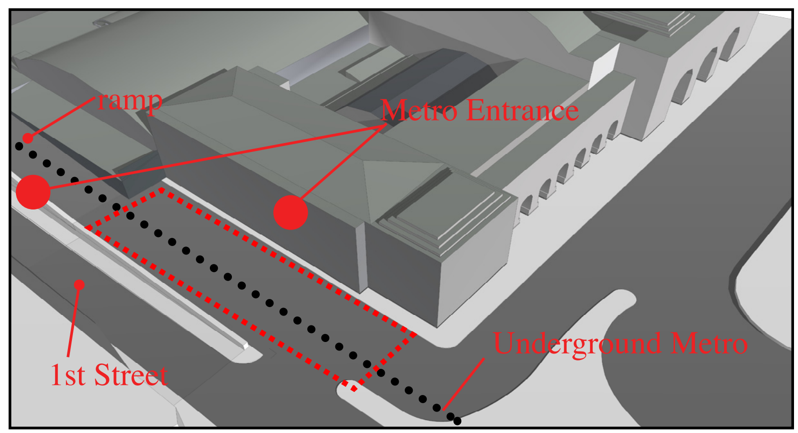


Figure 102. Union Station Bicycle Station Metro (Site)
The bicycle station is sited above the metro rail. Because of the grade change on 1st Street, the two entrances happen at different levels. The metro entrance on 1st Street goes underneath the ramp while the en-

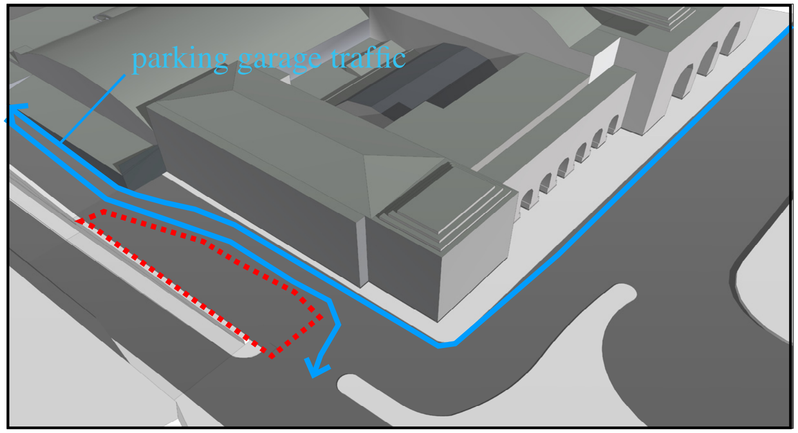


Figure 103. Union Station Bicycle Station Potential Site 1 (Site)
This potential site orients the bicycle station adjacent to 1st Street and situates the traffic moving to and from the parking garage adjacent to Union Station.

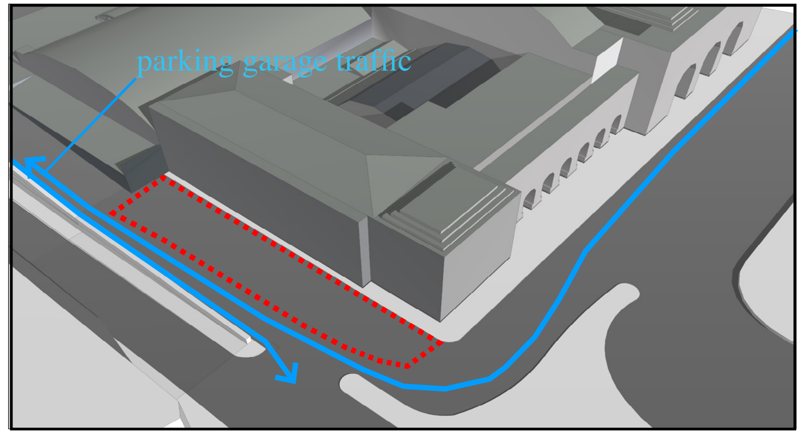


Figure 104. Union Station Bicycle Station Potential Site 2 (Site)
This potential site orients the bicycle station adjacent to Union Station and situates the traffic moving to and from the parking garage adjacent to 1st Street.

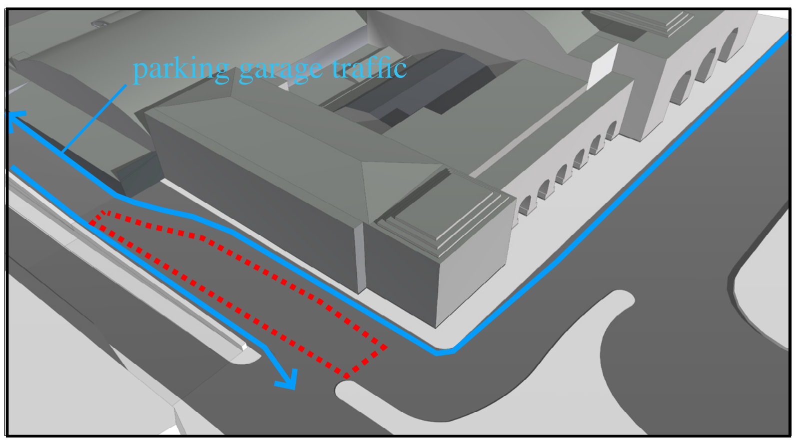


Figure 105. Union Station Bicycle Station Selected Site (Site)
This potential site orients the bicycle station between the parking garage traffic.

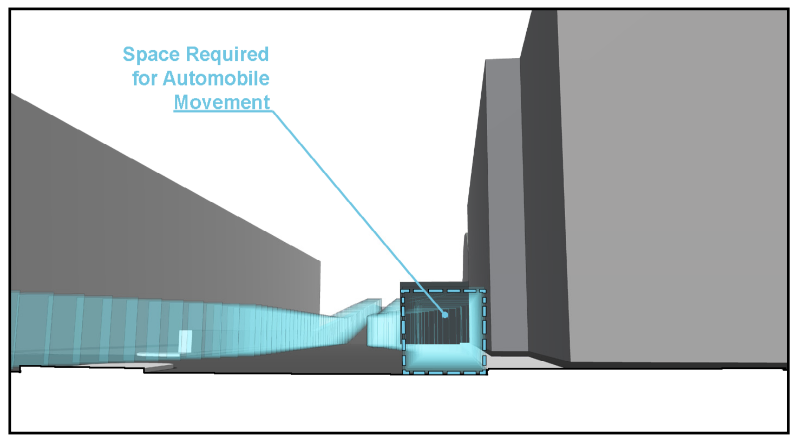


Figure 106. Union Station Bicycle Station Section of Selected (Site)
This potential site orients the bicycle station between the parking garage traffic. By locating the building here, it acts as a divider for the traffic and connects the bicycle station to plaza in front of Union Station.

Original Form-the original form is derived from the barrel vault located in the entry vestibule at the western side of Union Station.

.

Indirect Sunlight-the original form should shred to allow indirect sunlight to light the interior of the building by bouncing visible light onto the ceilings and reflecting it deep into the interior.

Direct Sunlight-the original form should shred to allow maximum direct sunlight to enter the building in the winter but prevent direct sunlight in the summer

Analysis-the analysis of the conditions occurs throughout the days of March 21st, June 21st, September 21st, and December 21st. March 21st, September 21st, and December 21st will describe a series of shredded barrel vaults that allow the maximum amount of direct sunlight to enter the building. June 21st will describe a series of shredded barrel vaults that block direct sunlight while allowing a maximum amount of indirect sunlight to enter the building. The final form is derived from this analysis with emphasis placed on the 12:00 pm to 2:00 pm.

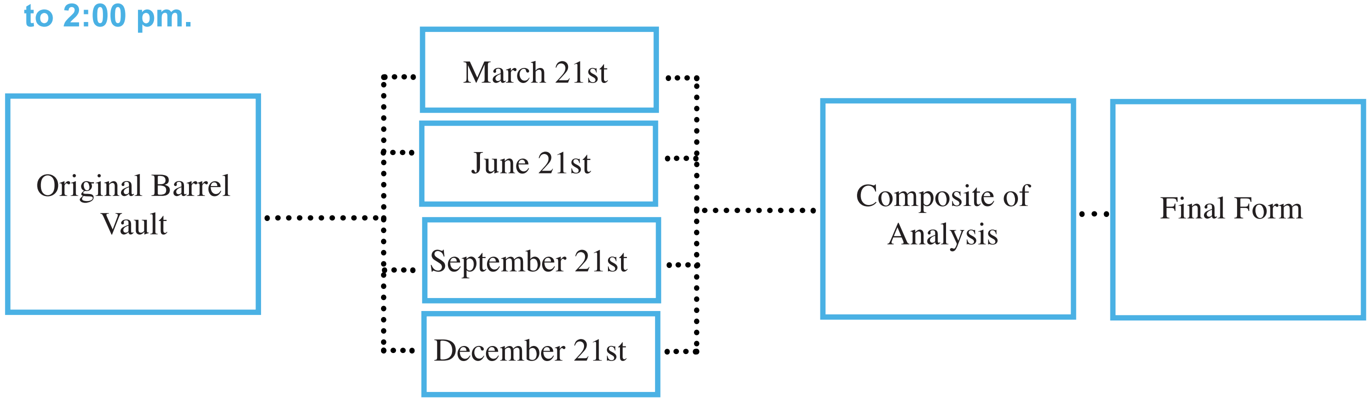


Figure 107. Union Station Bicycle Station Solar Constraint Design Process and Flow Cart (Sunlight/Solar Gain)
The sunlight/solar gain analysis is used to modify the barrel vault based on the specified solar conditions.

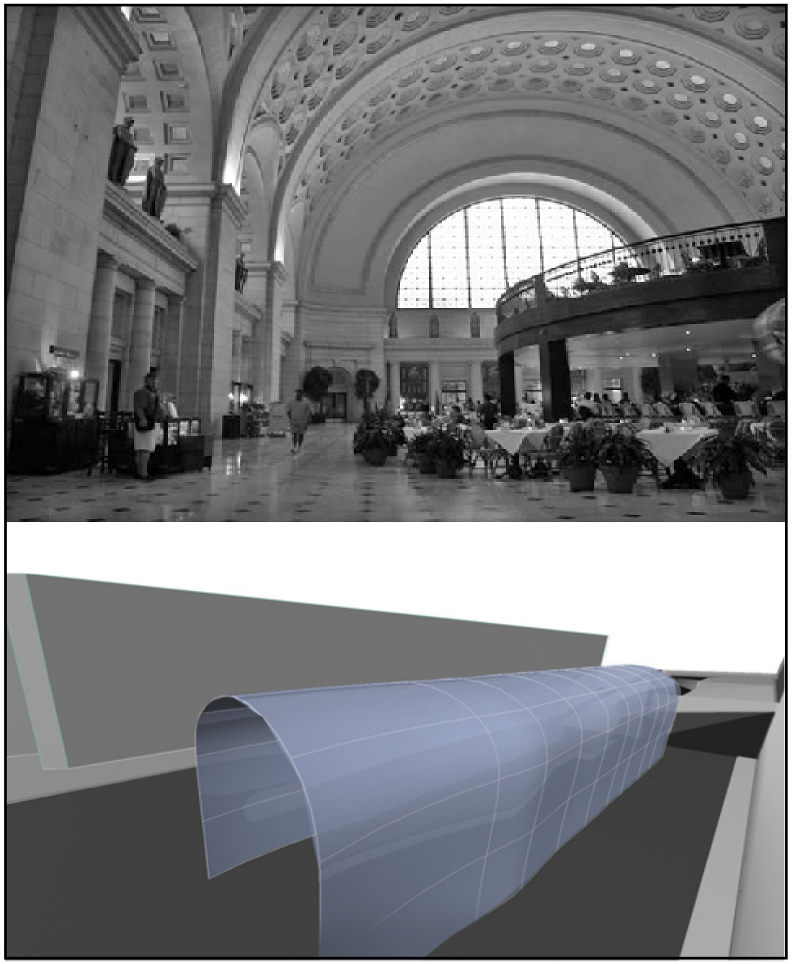


Figure 108. Union Station Bicycle Station Inspiration and Digital Representation of the Original Form (Sunlight/Solar Gain)
The bicycle station takes its form from Union Station, which is composed of a series of barrel vaults.

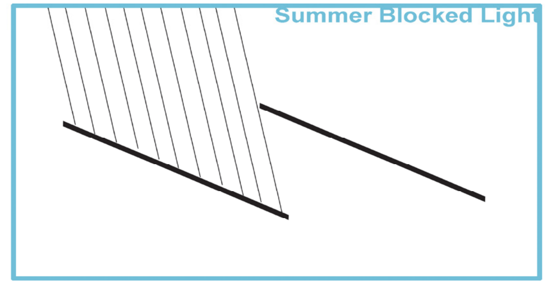


Figure 109. Reducing Solar Gain
The barrel vault can shred but still prevent direct sunlight from entering during the summer.

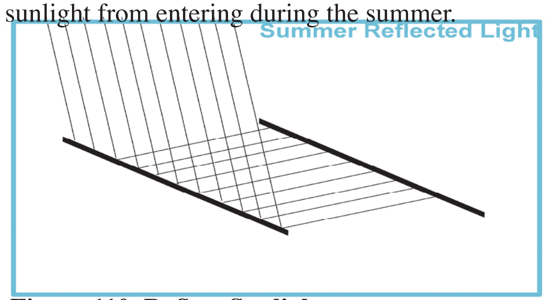


Figure 110. Reflect Sunlight
The barrel vault can shred and allow indirect sunlight to enter while blocking direct sunlight.

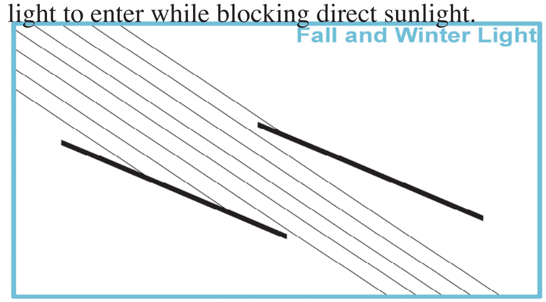


Figure 111. Allowing Solar Gain
The barrel vault can shred and allow direct sunlight to enter for the fall and winter months.

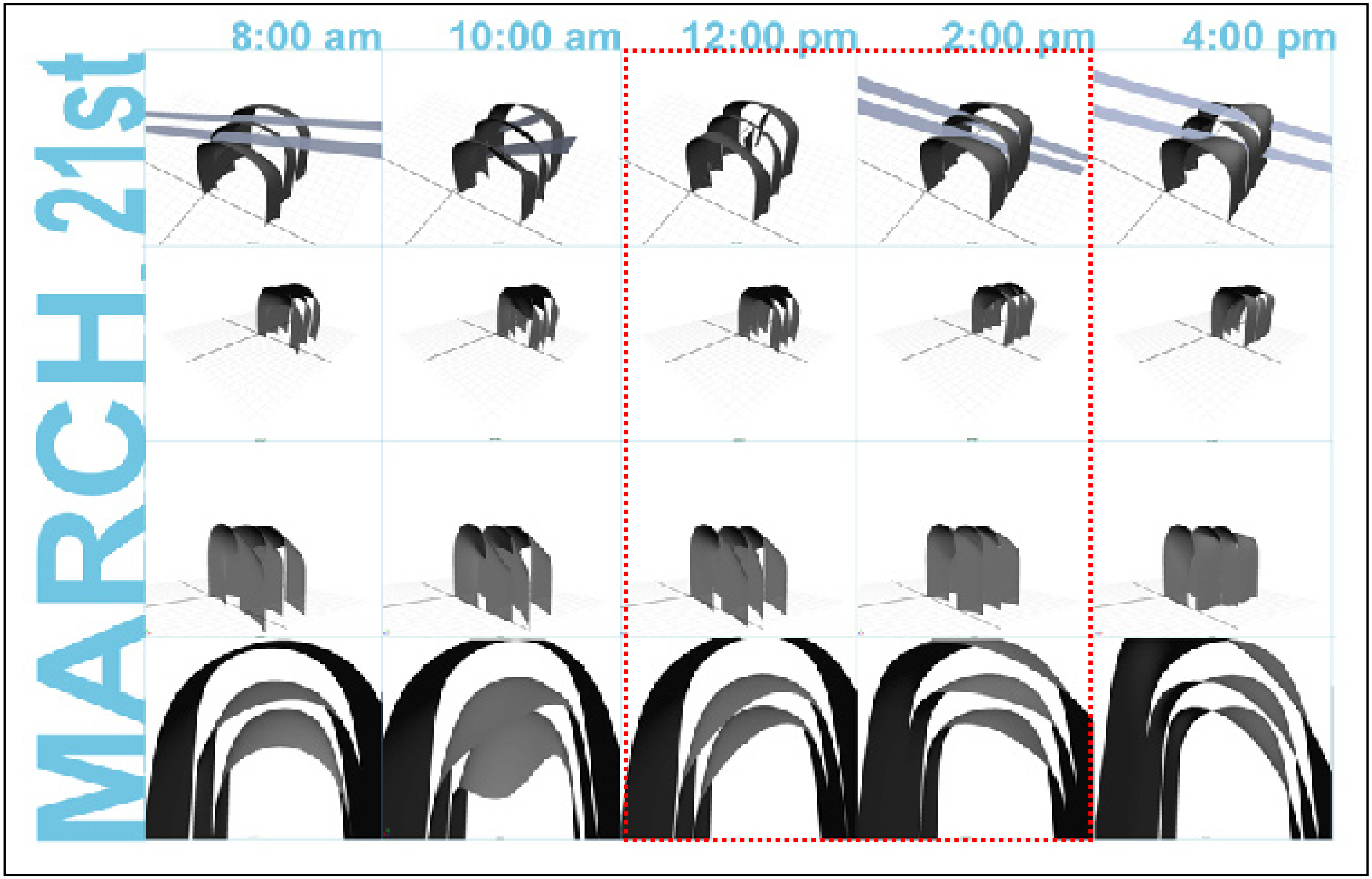


Figure 112. Union Station Bicycle Station Direct Sunlight Analysis March 21st (Sunlight/Solar Gain)
The barrel vault is shredded to allow as much direct sunlight to enter the building as possible. The analysis was performed every 2 hours from 8:00 am until 4:00 pm. The most important times of the day are from 12:00 pm to 2:00 pm as that is when the most solar gain can occur.

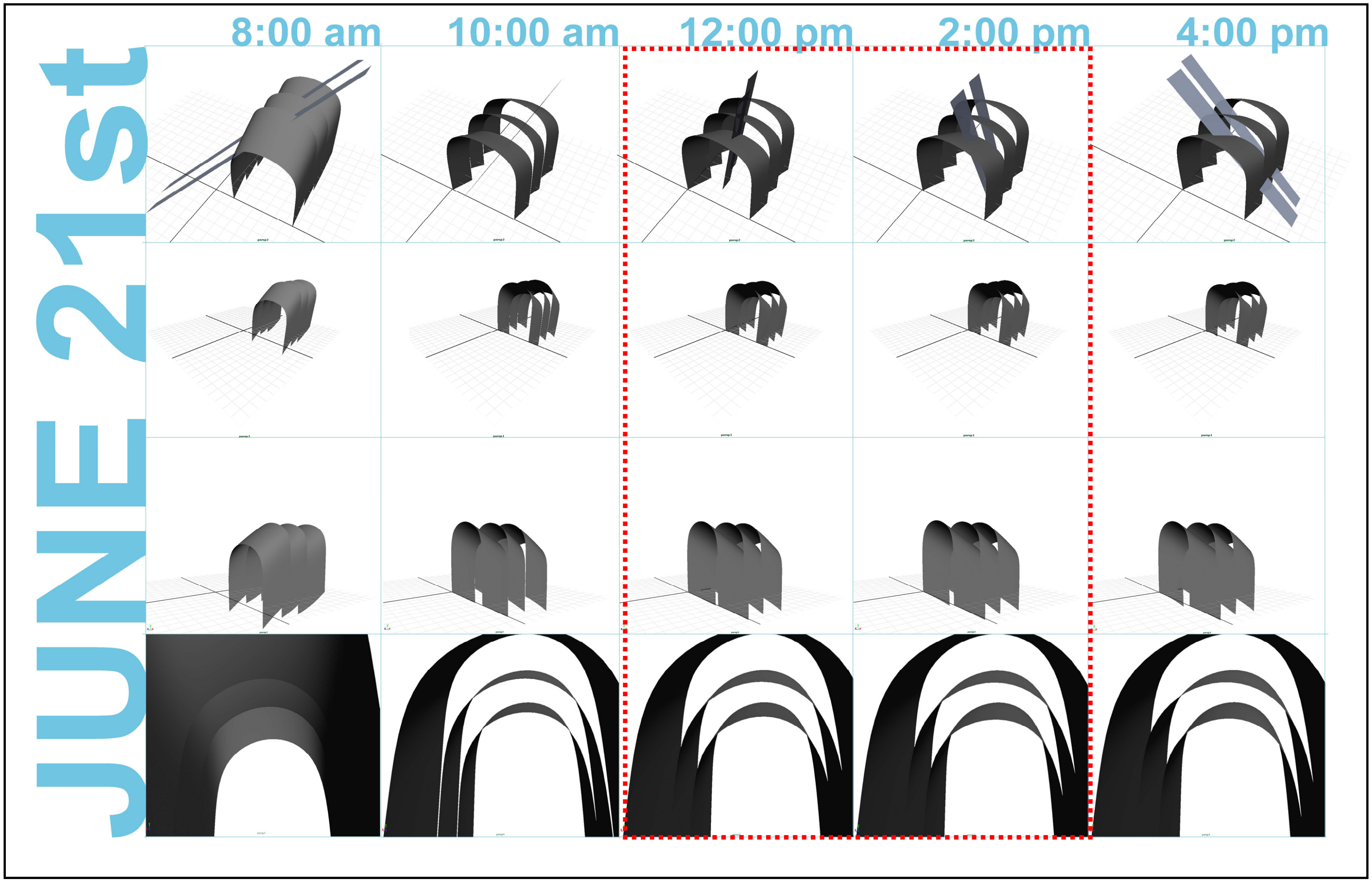


Figure 113. Union Station Bicycle Station Direct and Indirect Sunlight Analysis June 21st (Sunlight/Solar Gain)
The barrel vault is shredded to allow indirect sunlight to enter the building while blocking direct sunlight. The analysis was performed every 2 hours from 8:00 am until 4:00 pm. The most important times of the day are from 12:00 pm to 2:00 pm as that is when the most solar gain can occur.

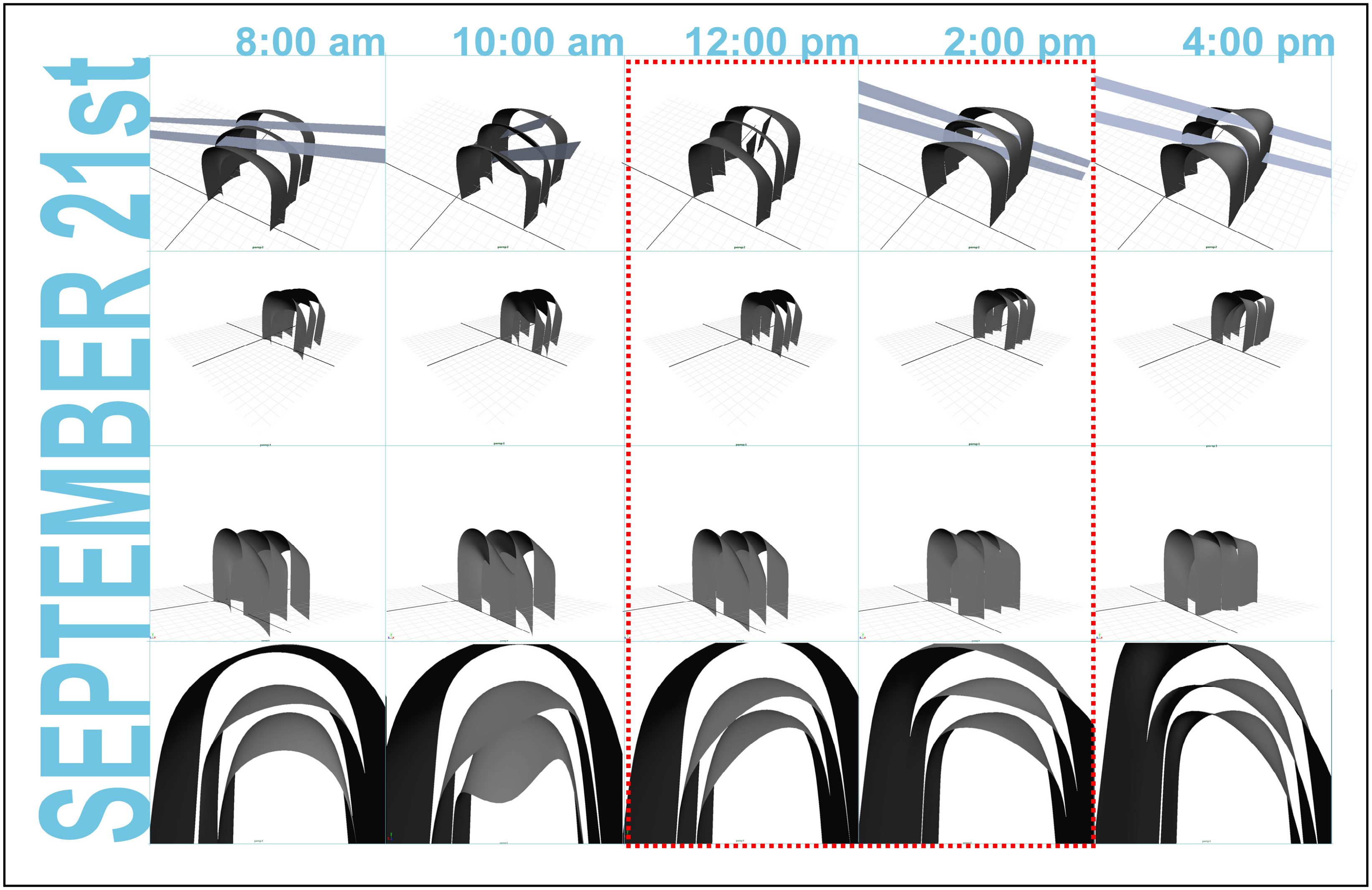


Figure 114. Union Station Bicycle Station Direct Sunlight Analysis September 21st (Sunlight/Solar Gain)
The barrel vault is shredded to allow as much direct sunlight to enter the building as possible. The analysis was performed every 2 hours from 8:00 am until 4:00 pm. The most important times of the day are from 12:00 pm to 2:00 pm as that is when the most solar gain can occur.

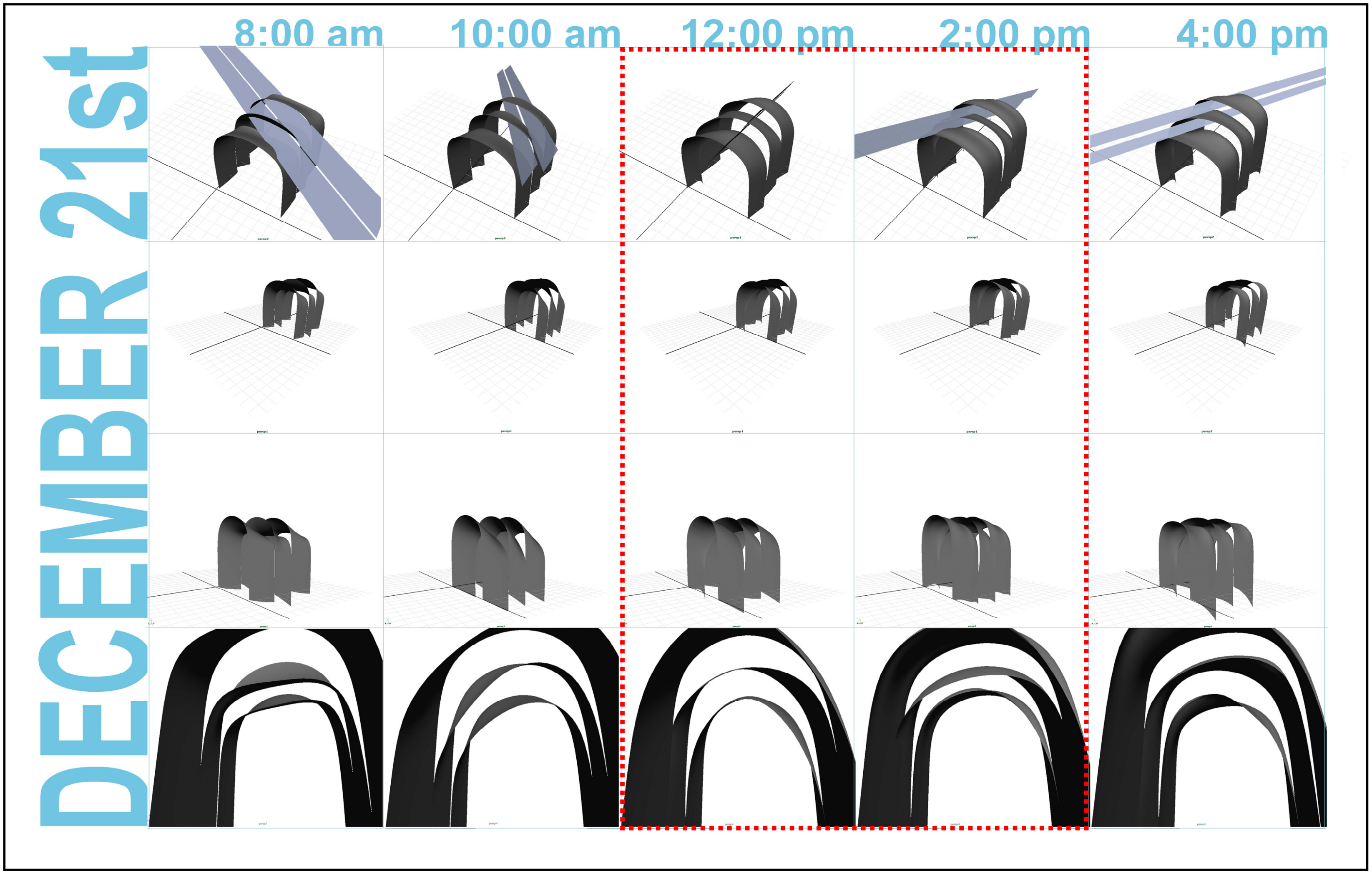


Figure 115. Union Station Bicycle Station Direct Sunlight Analysis December 21st (Sunlight/Solar Gain)
The barrel vault is shredded to allow as much direct sunlight to enter the building as possible. The analysis was performed every 2 hours from 8:00 am until 4:00 pm. The most important times of the day are from 12:00 pm to 2:00 pm as that is when the most solar gain can occur.

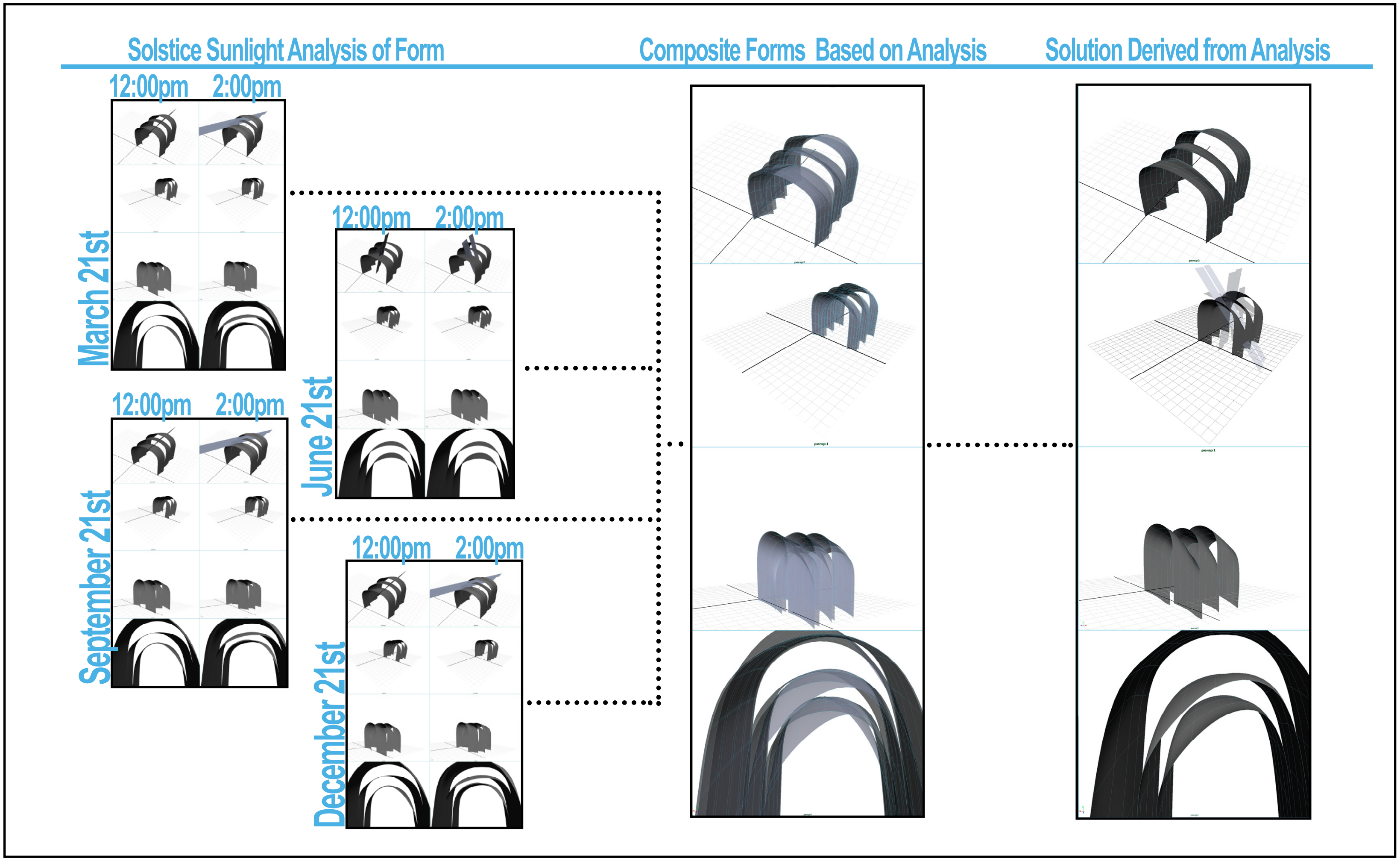


Figure 116. Union Station Bicycle Station Flow Diagram of Direct and Indirect Sunlight Analysis and Derivation of the Solution (Sunlight/Solar Gain)

The solution is derived from a composite of the forms created from the Solstice Sunlight Analysis. The resultant solution blocks light from entering the building on June 21st but allows light to enter from 12:00 am until 2:00 pm on March 21st, September 21st, and December 21st.

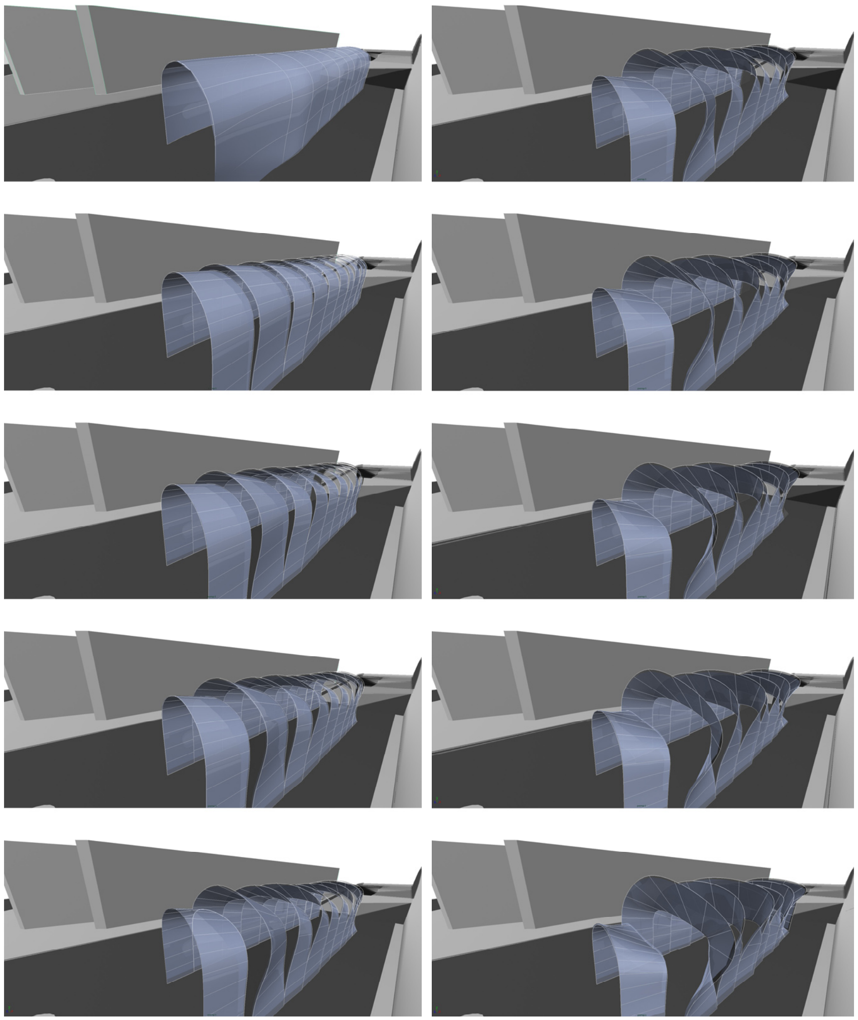


Figure 117. Union Station Bicycle Station Exterior Transformation of the Original Form to the Solution (Sunlight/Solar Gain)
The original barrel vaulted form is transformed into a form that blocks light from entering the building on June 21st but allows light to enter from 12:00 am until 2:00 pm on March 21st, September 21st, and December 21st.

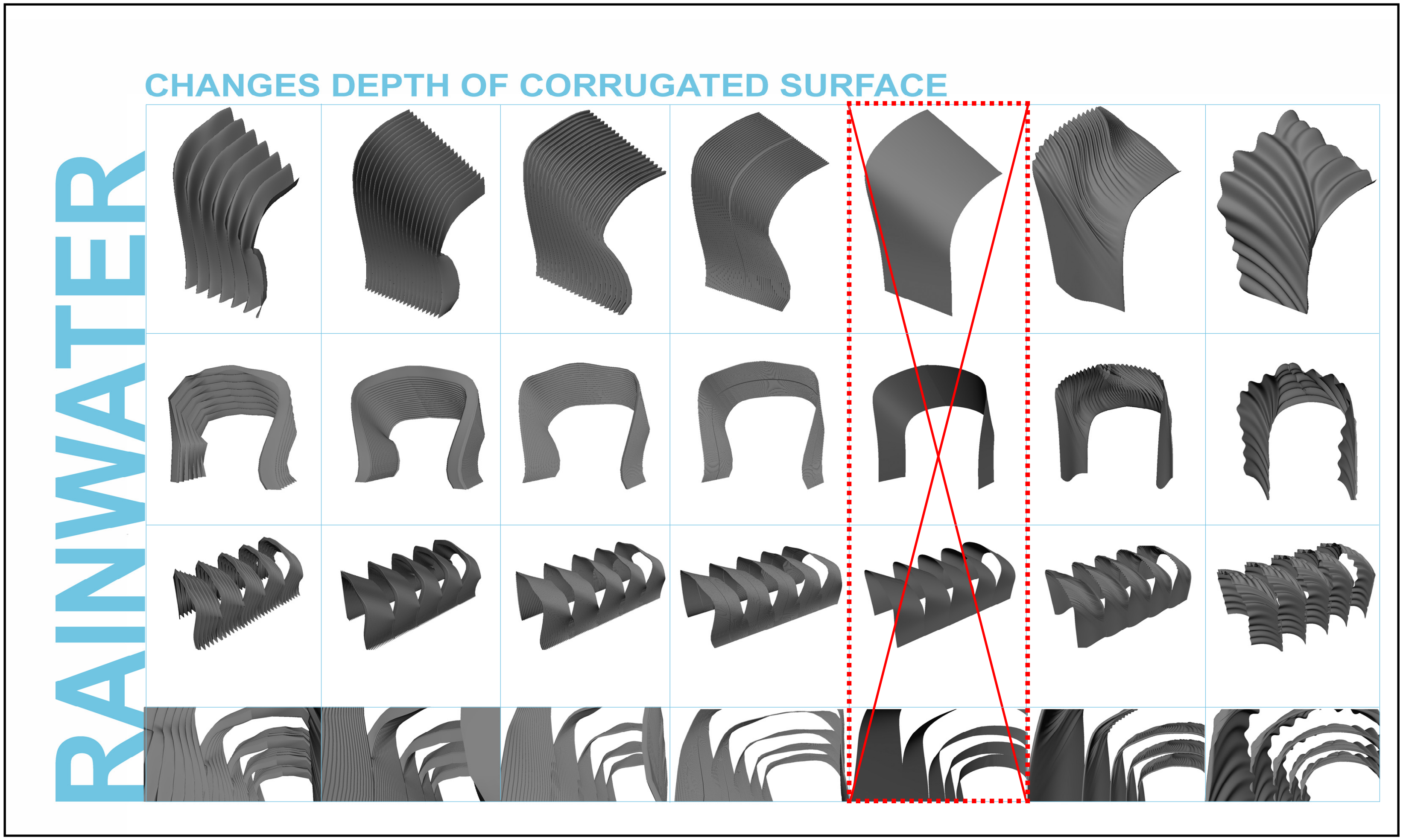


Figure 118. Union Station Bicycle Station Exploration of Surface Based on Rain Water Analysis (Rain Water and Material)
The form is tested to examine how rain water moves across its surface. Since the building is without glazing and is open to the air, rain water needs to move to the edges of the building away from the interior. The form that was derived from the sunlight analysis allows water to flow into the building. The use of carbon fiber as construction material allows the possibility for the surface to take a corrugated geometry. A series of possible solutions is explored based on the depth, number, and direction of the corrugation.

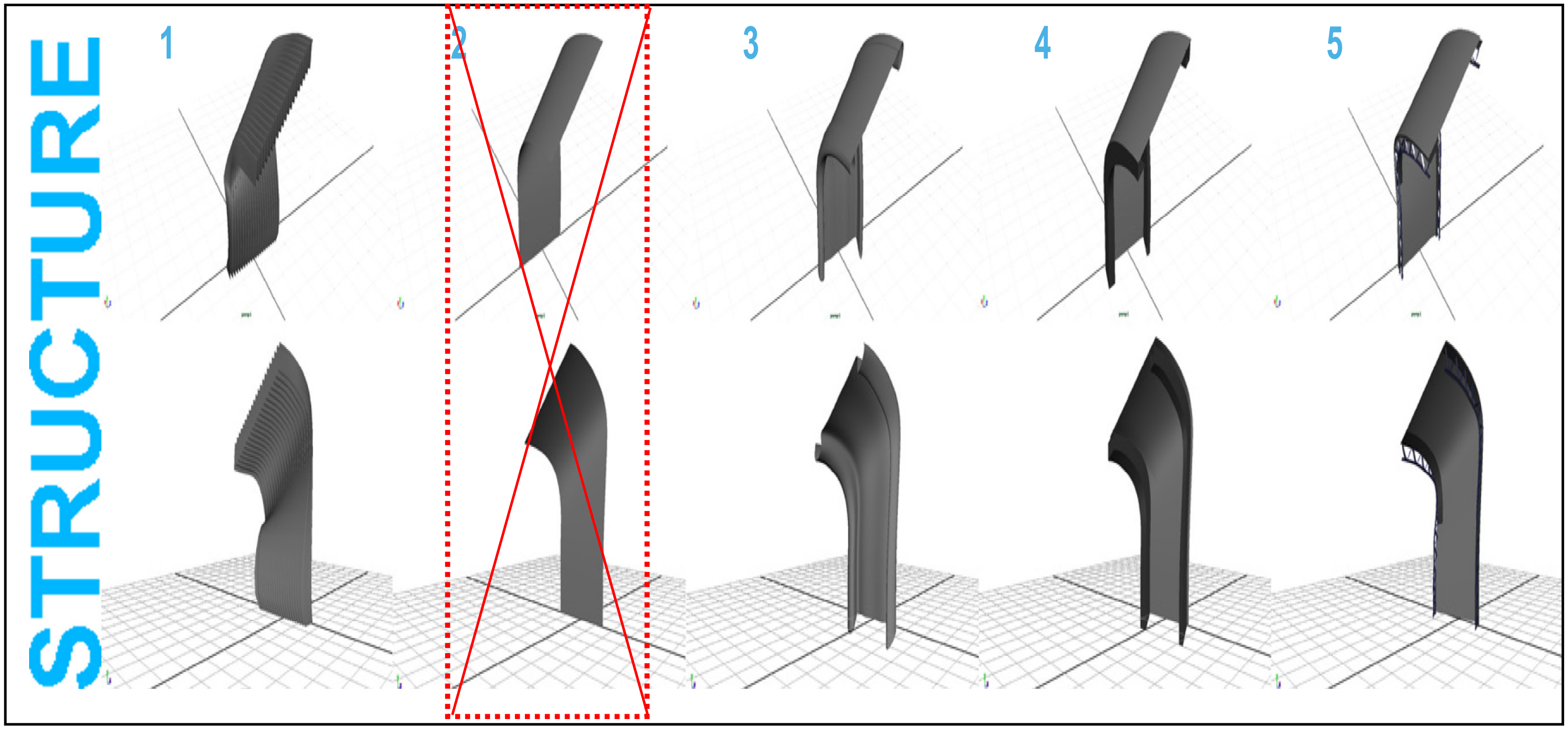
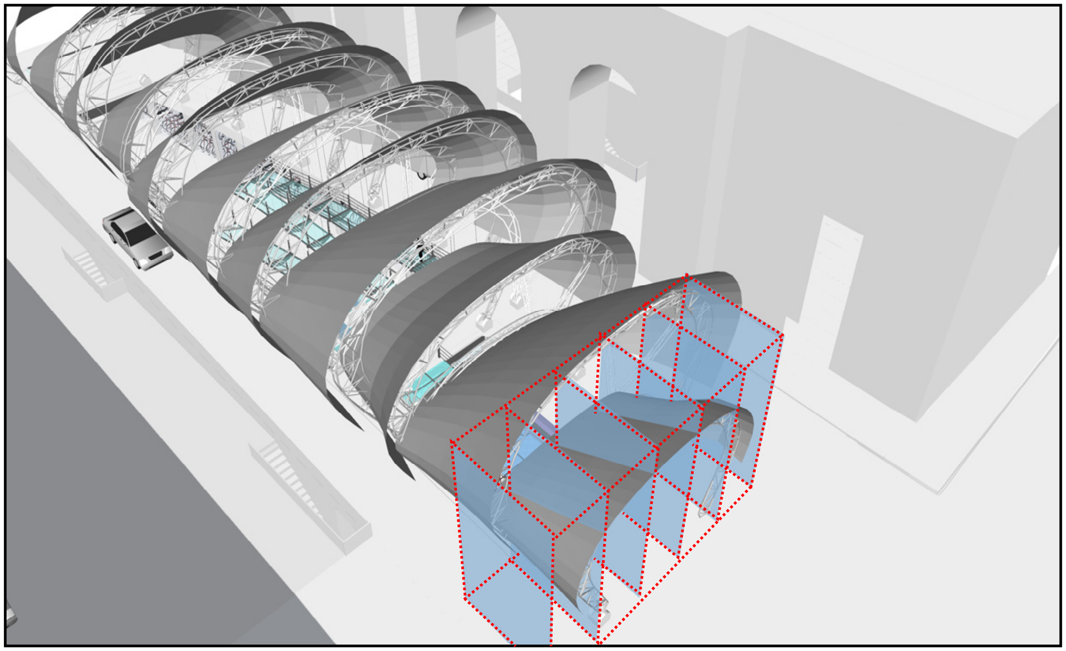


Figure 119. Union Station Bicycle Station Surface Exploration of Potential Structure (Structure and Material)

Potential structural systems are explored. 1- The use of carbon fiber allows the surface to take a structural form that corresponds to the corrugation explored in the rain water exploration. 2- The carbon fiber form derived from the sunlight analysis is too thin to be structural. Additional structure is needed. 3- The continuous carbon fiber surface incorporates a beam or birder in its geometry. 4- The carbon fiber skin is attached to a steel beam or box girder. 5- The carbon fiber skin is attached to a steel truss system.



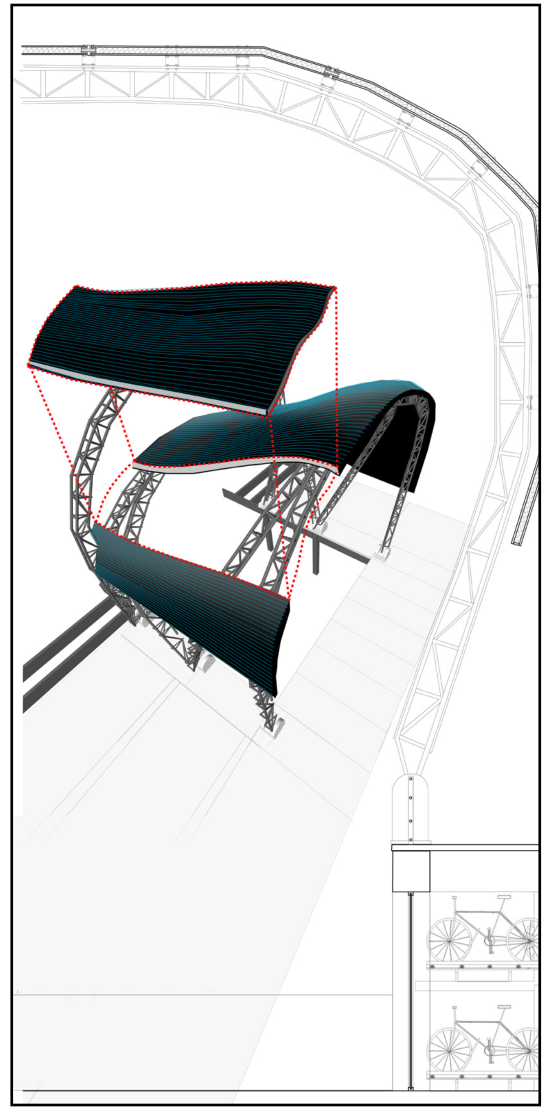


Figure 120 and 121. Union Station Bicycle Station Building Surface Fabrication and Assembly (Structure, Material, Fabrication, Assembly)

In order to be fabricated and delivered to the site, the surface is reduced to a series of panels that are small enough to be shipped and easily assembled. The surface is broken down by applying a grid to the surface. The grid relates directly to requirements of the reusable form work used to fabricate the panels. The carbon fiber insulation sandwich panels are fabricated off-site and delivered by truck. Once on site, the lightweight panels are easily hoisted up and attached to the truss structure.

Figure 122. Union Station Bicycle Station Site Plan

The bicycle station is located on the western side of Union Station along 1st Street. It is located along the Metropolitan Trail and serves as a connector between bicycling and other modes of transportation. It is situated apart from Union Station as an object building so that it serves as a symbol for bicycling in Washington D.C.

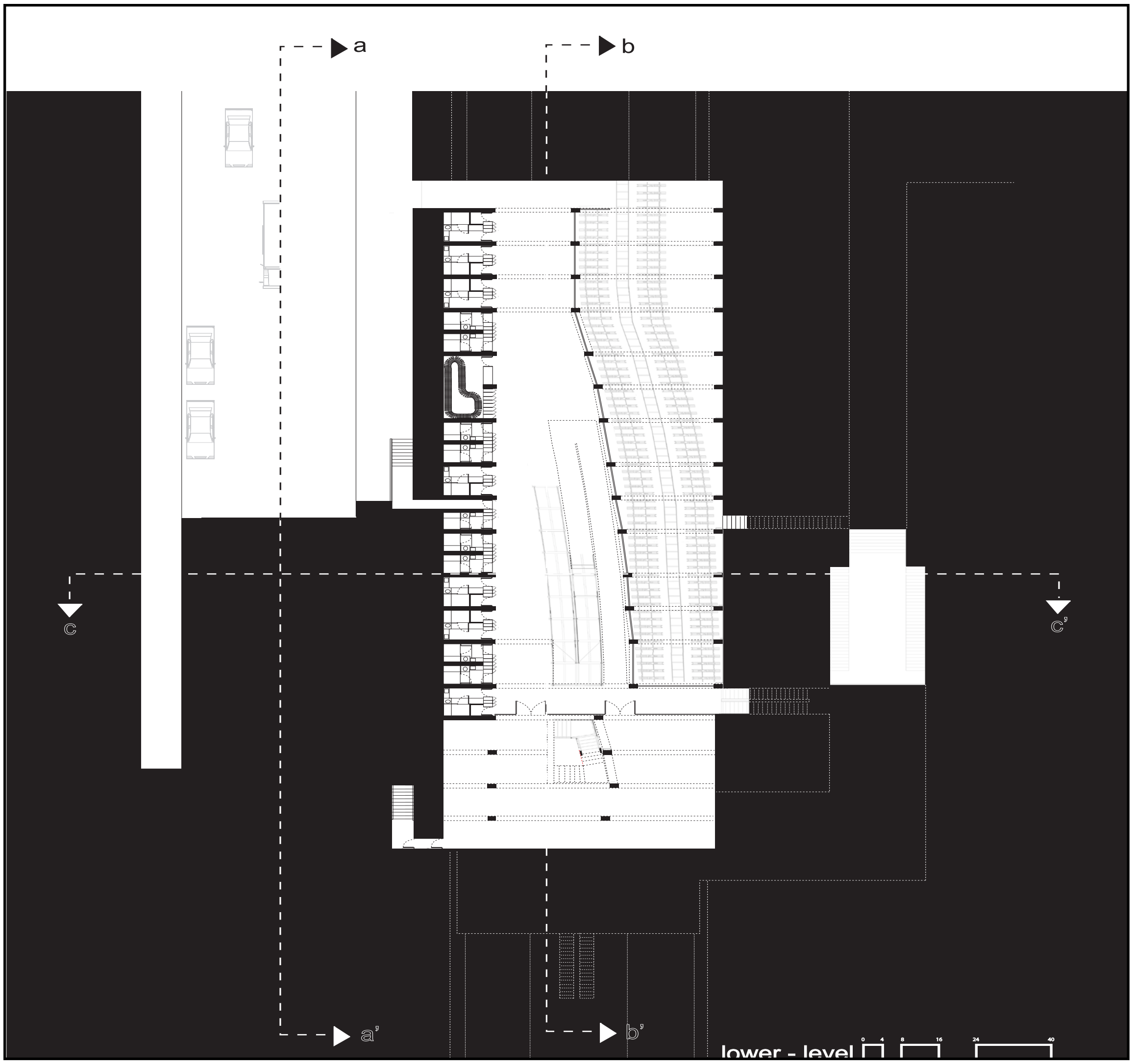


Figure 123. Union Station Bicycle Station Lower Level Plan

The bicycle station is entered from 1st Street and exists below the roadway that goes to the parking garage. The transformation from bicycling to walking begins when the commuter first enters. Upon entering the commuter dismounts the bicycle and stores it in the automated storage system. The commuter then proceeds to the dry cleaners, showers and lockers area. After showering the commuter can either exit up the ramp to the cafe and plaza or exit below to the metro rail.

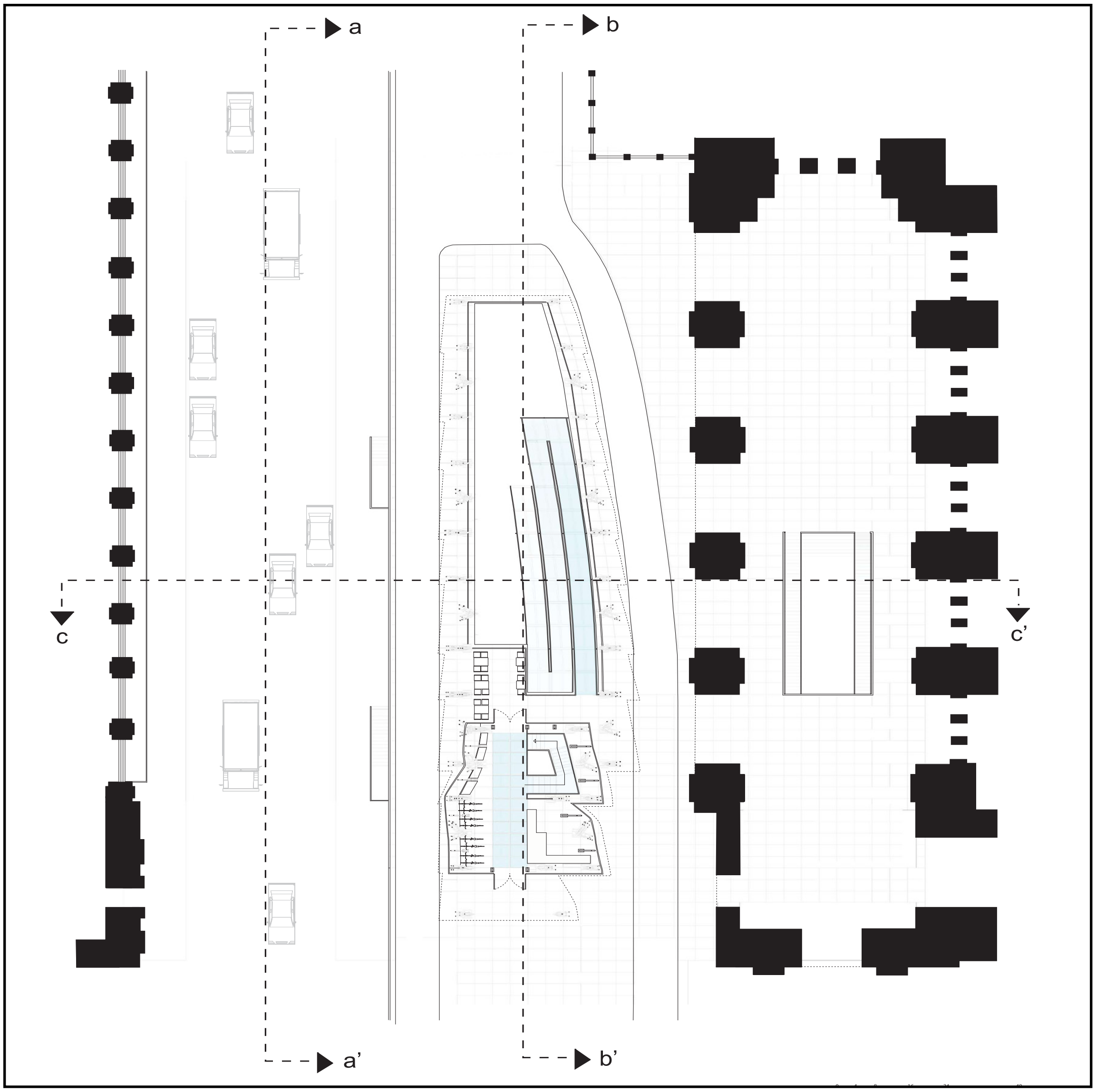


Figure 124. Union Station Bicycle Station Upper Level Plan
The upper level of the building consists of a bicycle rental area, cafe, and seating area. Its purpose is to be an advocate for bicycling in Washington D.C. It does this through providing information and bicycles for people to explore Washington D.C.

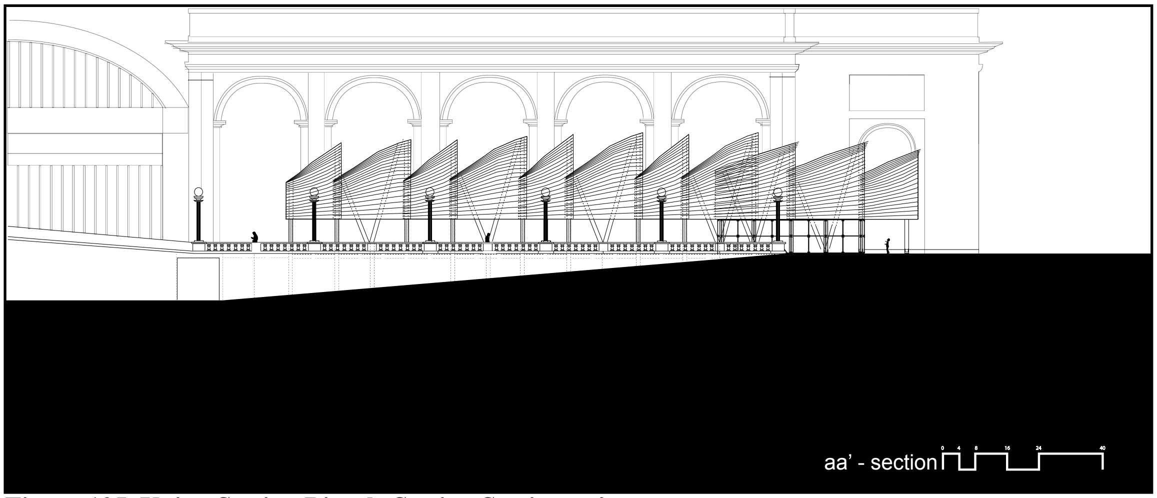


Figure 125. Union Station Bicycle Station Section aa'
Because of the sloping condition off 1st Street, the bicycle station has the ability to be designed with two levels that both can be entered on grade.

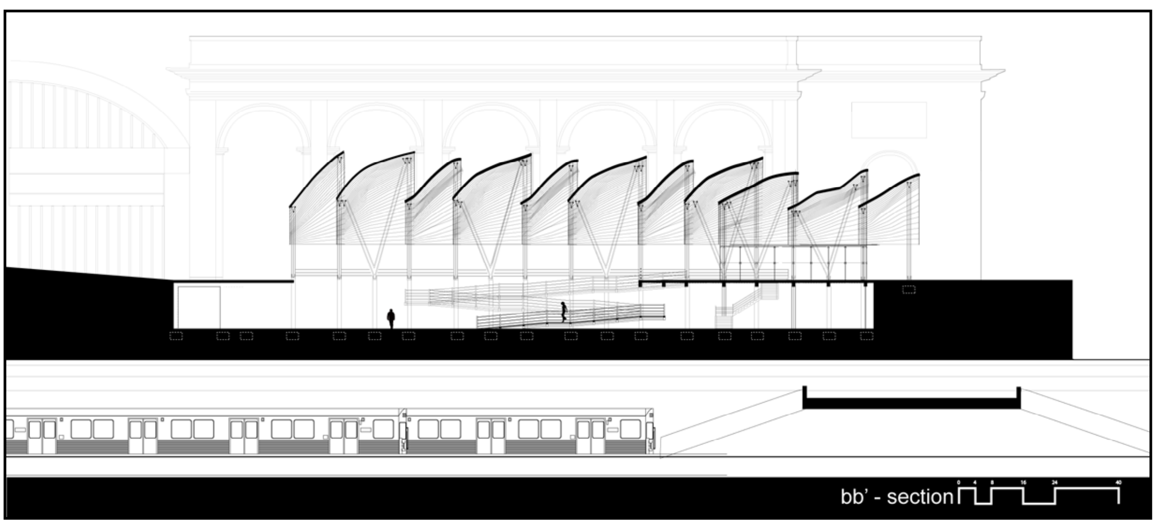


Figure 126. Union Station Bicycle Station Section bb'
The bicycle station connects to the metro station. The plaza above is connected through the suspended ramp. The canopy of the bicycle station is designed to block sunlight during the summer but allow in sunlight during the fall and winter months

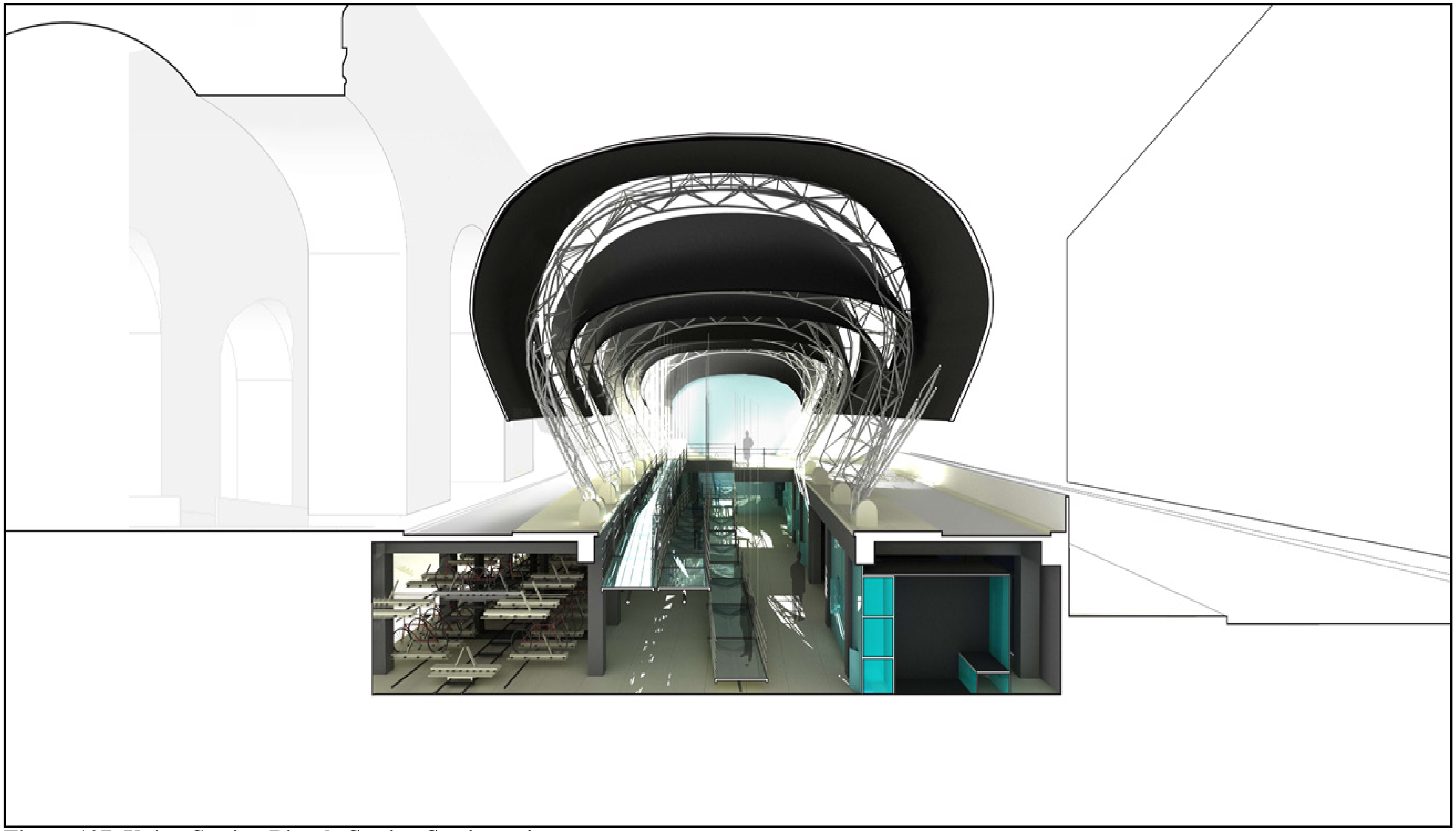


Figure 127. Union Station Bicycle Station Section cc'

The bicycle station is located between the entry and exit to the Union Station parking garage. The showers and lockers are inserted below the exit ramp while the bicycles are automatically stored under the entry ramp. The glass ramp suspended from the truss structure connects the upper and lower levels of the building. The truss also supports the roof canopy. The canopy is made of pre-fabricated carbon fiber honeycomb sandwich panel which extremely light weight but strong. The canopy allows direct light in during the fall and winter months but blocks it during the summer.

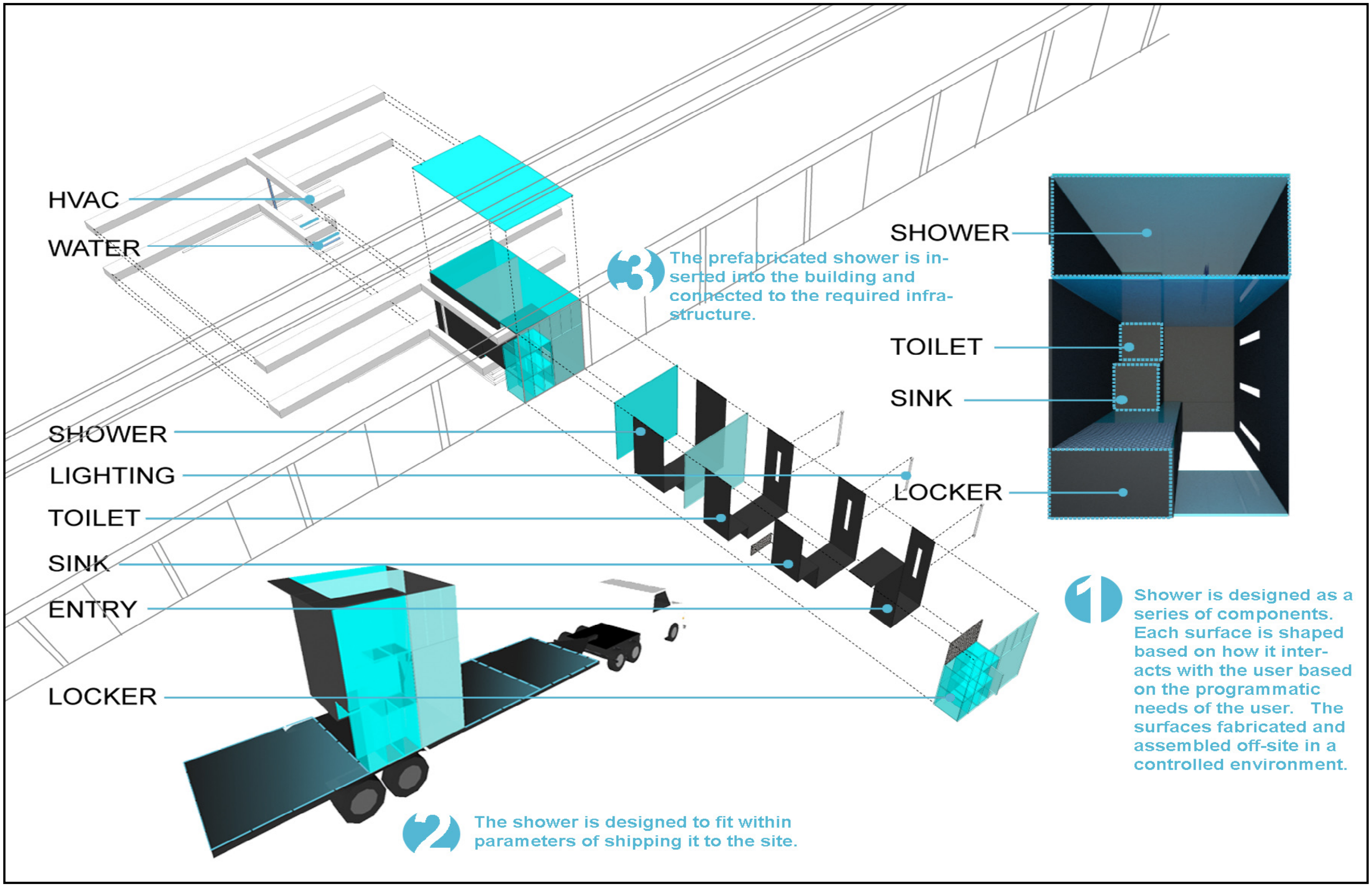


Figure 128. Union Station Bicycle Station Shower (Site, Program, Structure, Material, Fabrication, and Assembly)
Designed to be prefabricated and assembled off-site, delivered by truck, and inserted underneath the existing roadway, the shower surface is made of carbon fiber material which reacts and changes its form based on programmatic requirements

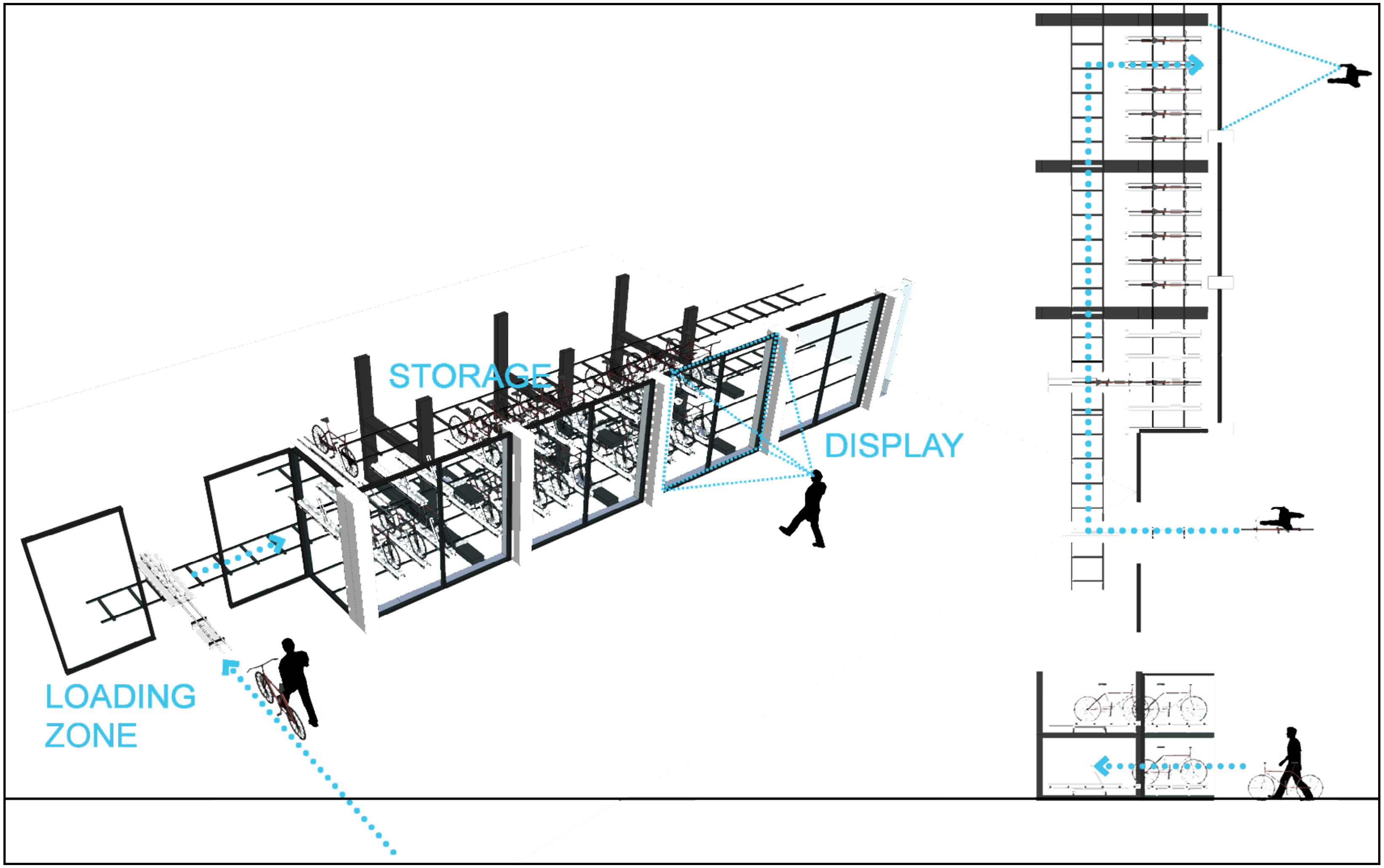


Figure 129. Union Station Bicycle Station Automatic Storage Rack

The automatic storage rack allows a bicyclist to automatically store his bicycle. When the bicyclist arrives to the loading zone he requests a storage rack. The rack is brought to the loading zone along a track for the bicyclist to load his bicycle. Once the bicycle is loaded, it is taken down the track and inserted into an available spot. The bicycle is stored so that it is on display and visually accessible but not physically accessible.

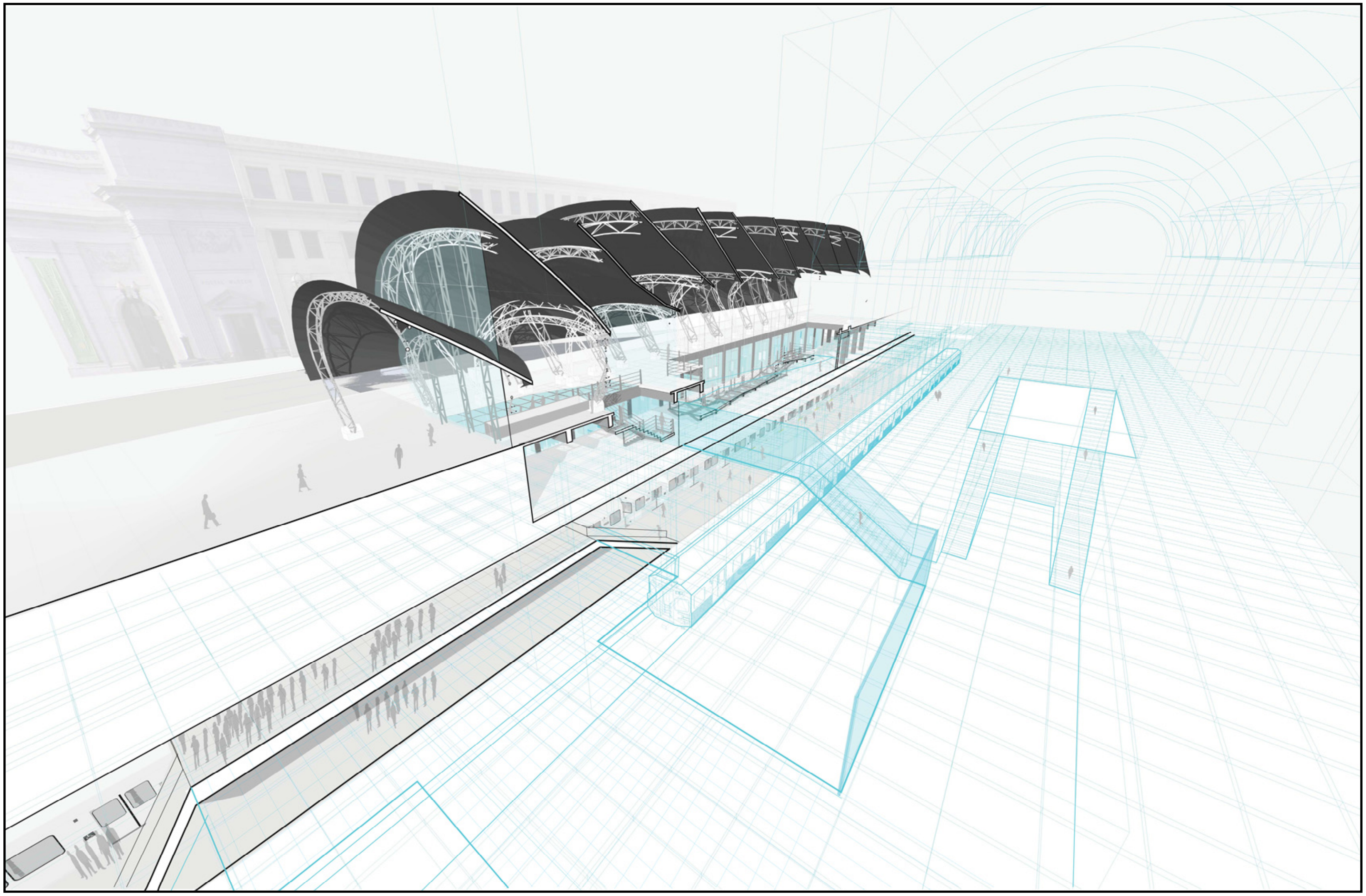


Figure 130. Union Station Bicycle Station Section
The bicycle station acts as a connector by allowing access to Union Station and the metro station below.

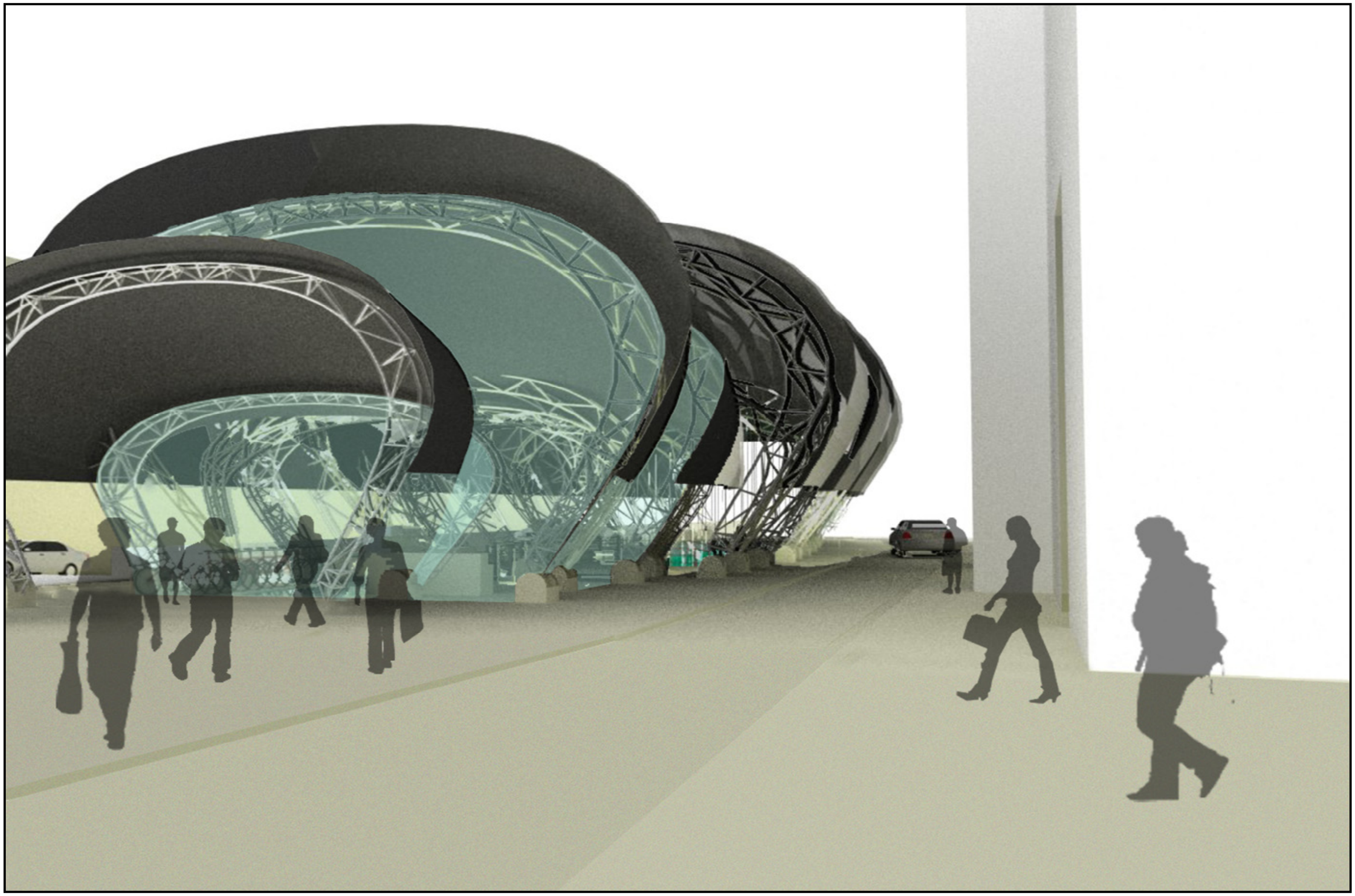


Figure 131. Union Station Bicycle Station Exterior View

View of the Union Station Bicycle Station from the upper level looking at Rental Shop, Cafe, and entry ramp to the parking garage.

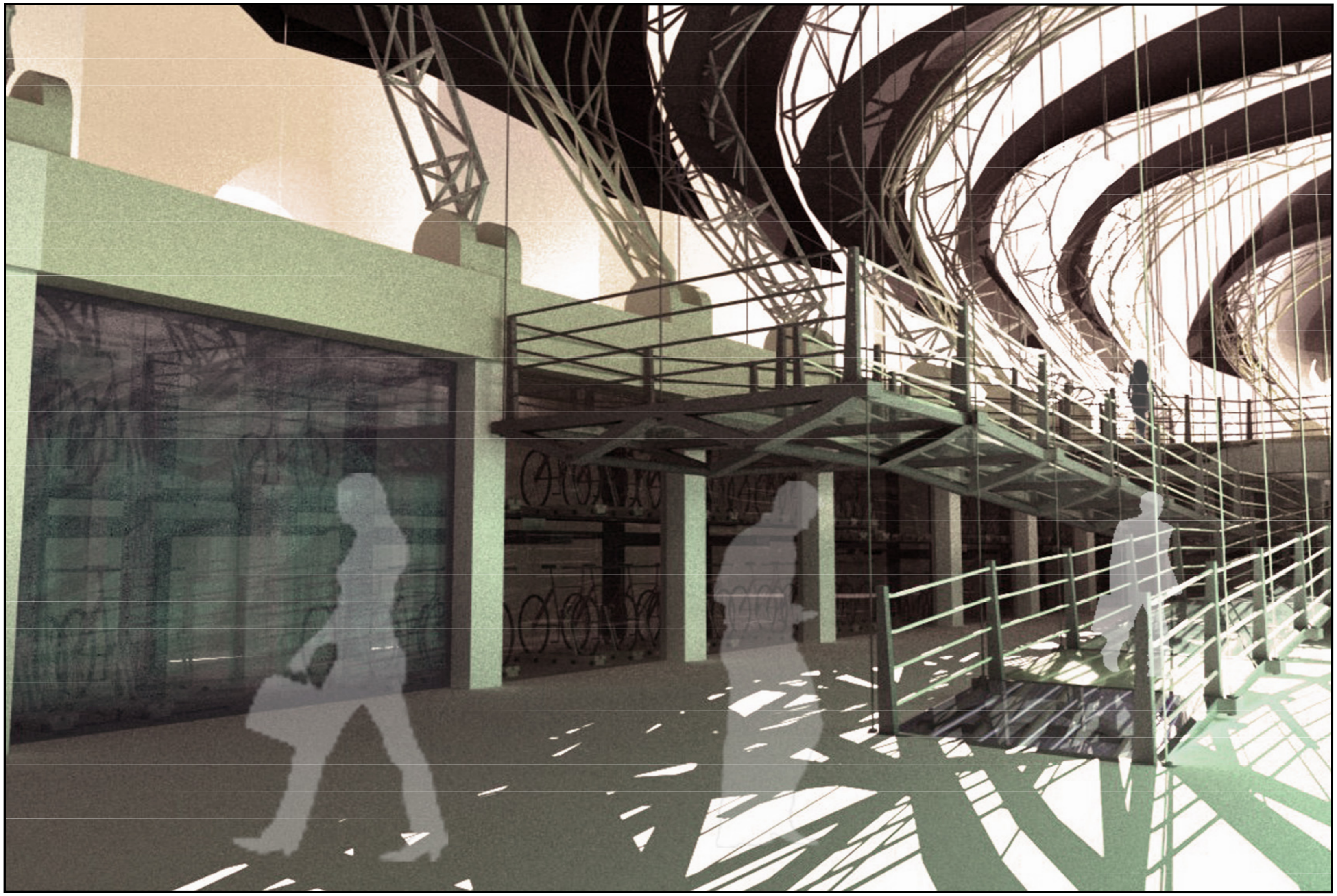


Figure 132. Union Station Bicycle Station Interior View of the Storage Racks
View from the lower level of the Union Station Bicycle Station showing the ramp and display of the storage racks

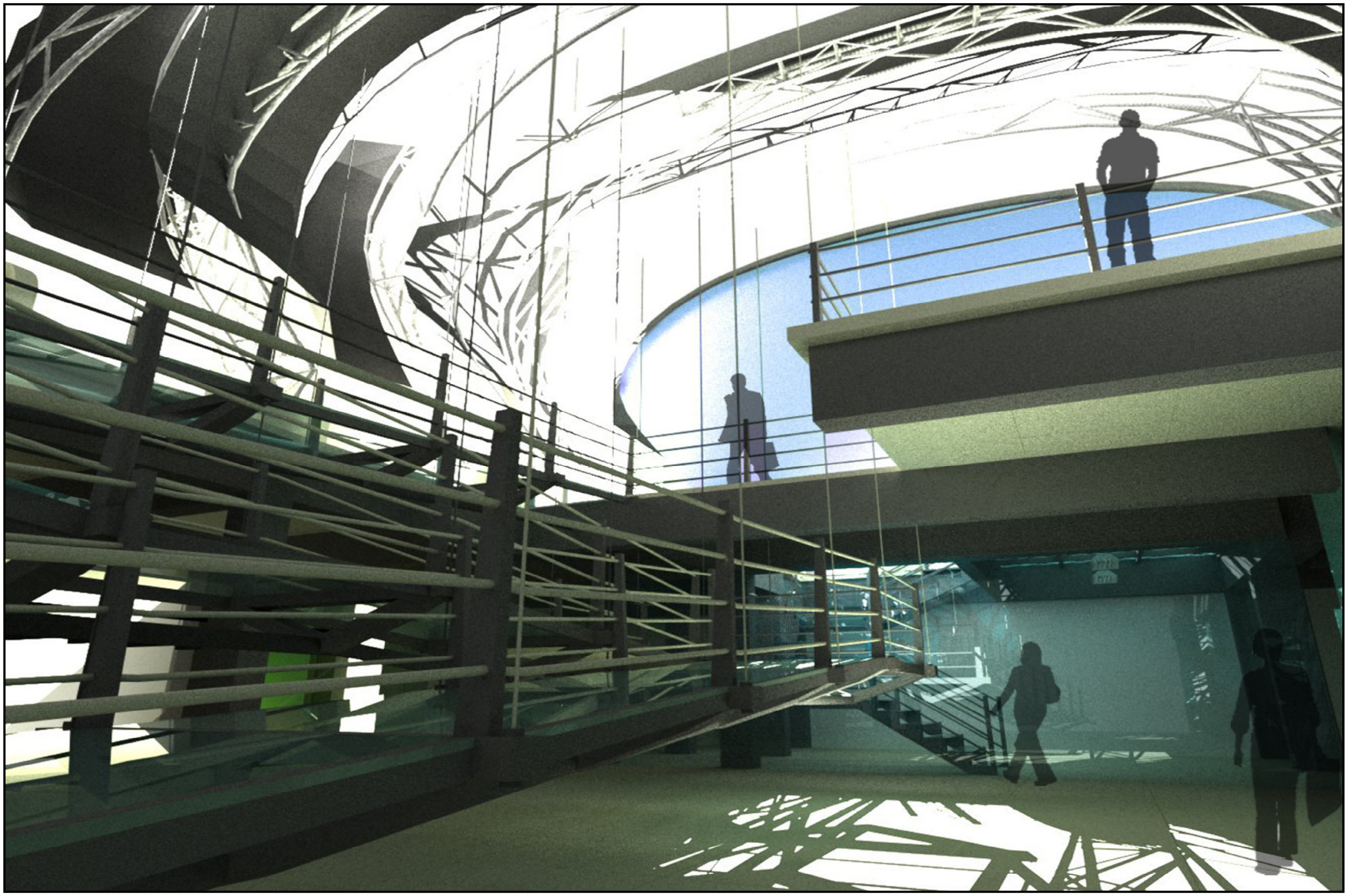


Figure 133. Union Station Bicycle Station Interior View of the Ramp and Bicycle Shop
View from the lower level of the Union Station Bicycle Station showing the ramp, bicycle shop, and seating area above.

Figure 134. Union Station Bicycle Station Interior View of the Ramp and Bicycle Rental Area and Cafe
View from the ramp looking at the Rental Shop and Cafe, and seating area for the cafe.

Conclusion

In conclusion this thesis was an exploration of complex geometric forms. This exploration led not only to a study of the current application of technology and material but also looked outside of architecture into other design professions. It looked at the aeronautical and automobile industries use of new technology and material and explored how they could be applied to architecture. Specifically carbon fiber composites were analyzed and applied to architecture. This application of carbon fiber needed an adaptation to the way it was mad in order to make it more sustainable. A reusable form work was developed so that complex forms could be created in a sustainable way.

The application of new technology raises the same questions that architects have had to answer for years. How does architecture progress in light of new technology and materials? Although there is not one answer for this, architects need to look at the new technology and appropriately apply it. We needed to define what an appropriate application of the technology and explore how it can be applied to different contexts.

With new technology, the role of the architect has evolved. What does the role of the architect become with the implementation of this new technology? With the use of parametric design, architects need to be careful not to become too reliant on the new technology to create solutions on its own.

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