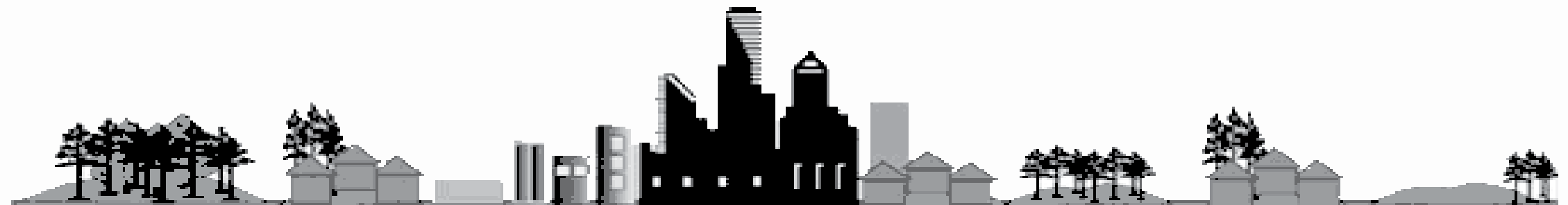


URBAN HEAT ISLAND

ENVD 3300 Praxis Spring 2012

Daryoosh Ardalan | Christy Horber | Stephen Ricciardelli



Boulder Valley Comprehensive Plan

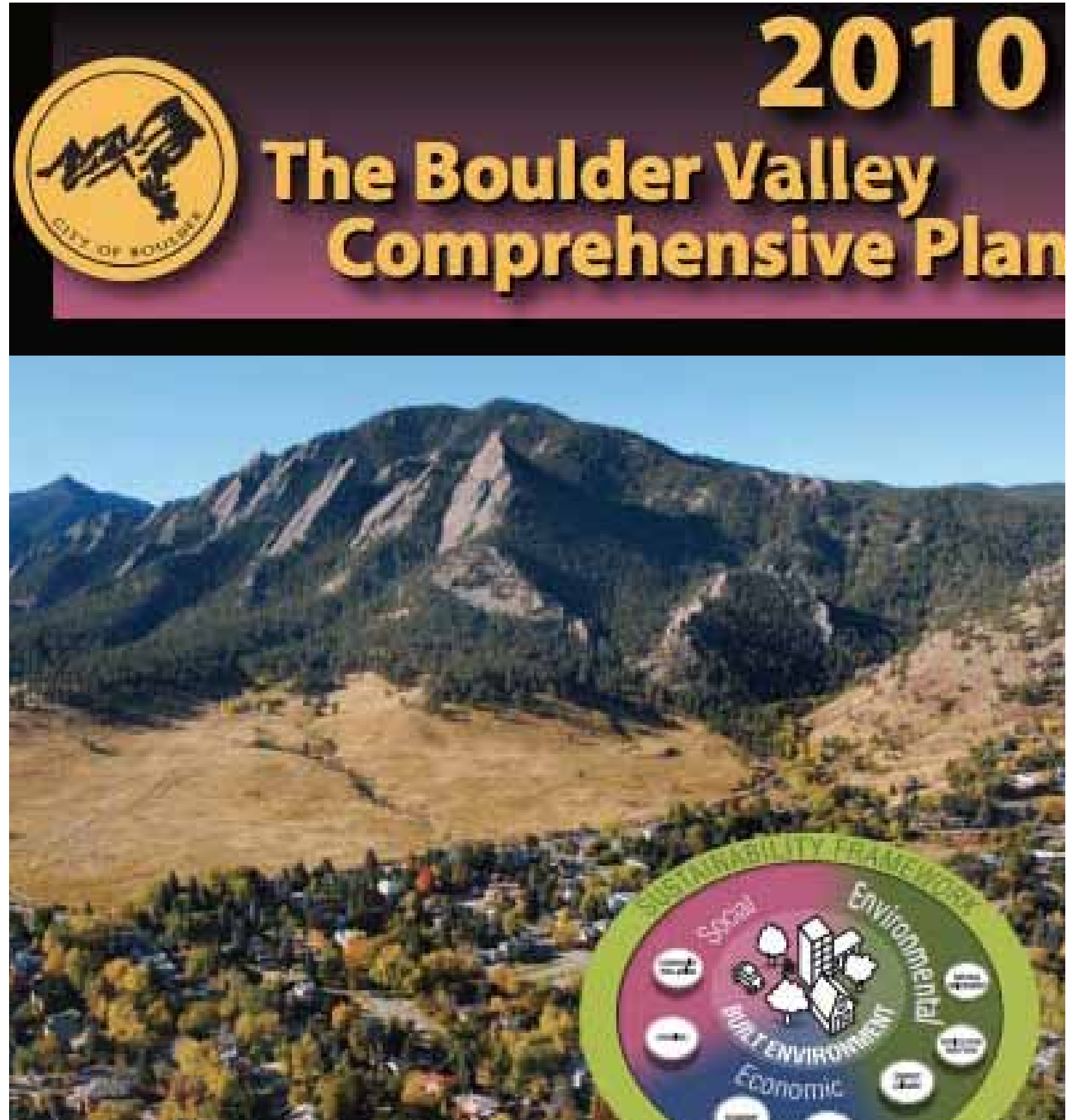
The City of Boulder's Planning Department has been working on an ongoing project to identify sustainability indicators that can quantitatively and qualitatively measure the city's progress in meeting the goals in Boulder Valley Comprehensive Plan (BVCP). A major theme throughout the BVCP is sustainability and sustainable urban form. The City of Boulder defines sustainable urban form as:

1. Compact
2. Complete
3. Connected
- 4. Distinct and Green**
5. Inclusive

The following project focuses on distinct and green urban form, within the context of Urban Heat Island. Results from the project suggest that by identifying areas with abnormally high or low heat and using appropriate mitigation strategies, the area will not only be cooler, but it will also be distinct and green.

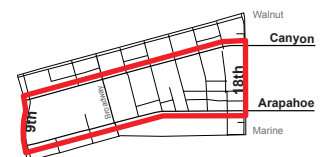
Urban Heat

The EPA describes Urban Heat as "built up areas that are hotter than nearby rural areas. The annual mean air temperature of a city with 1 million people or more can be 1.8–5.4°F (1–3°C) warmer than its surroundings. Heat islands can affect communities by increasing summertime peak energy demand, air conditioning costs, air pollution and greenhouse gas emissions, heat-related illness and mortality, and water quality". (<http://www.epa.gov/hiri/>)



URBAN HEAT

Purpose and Background

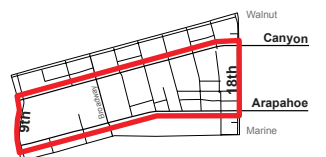
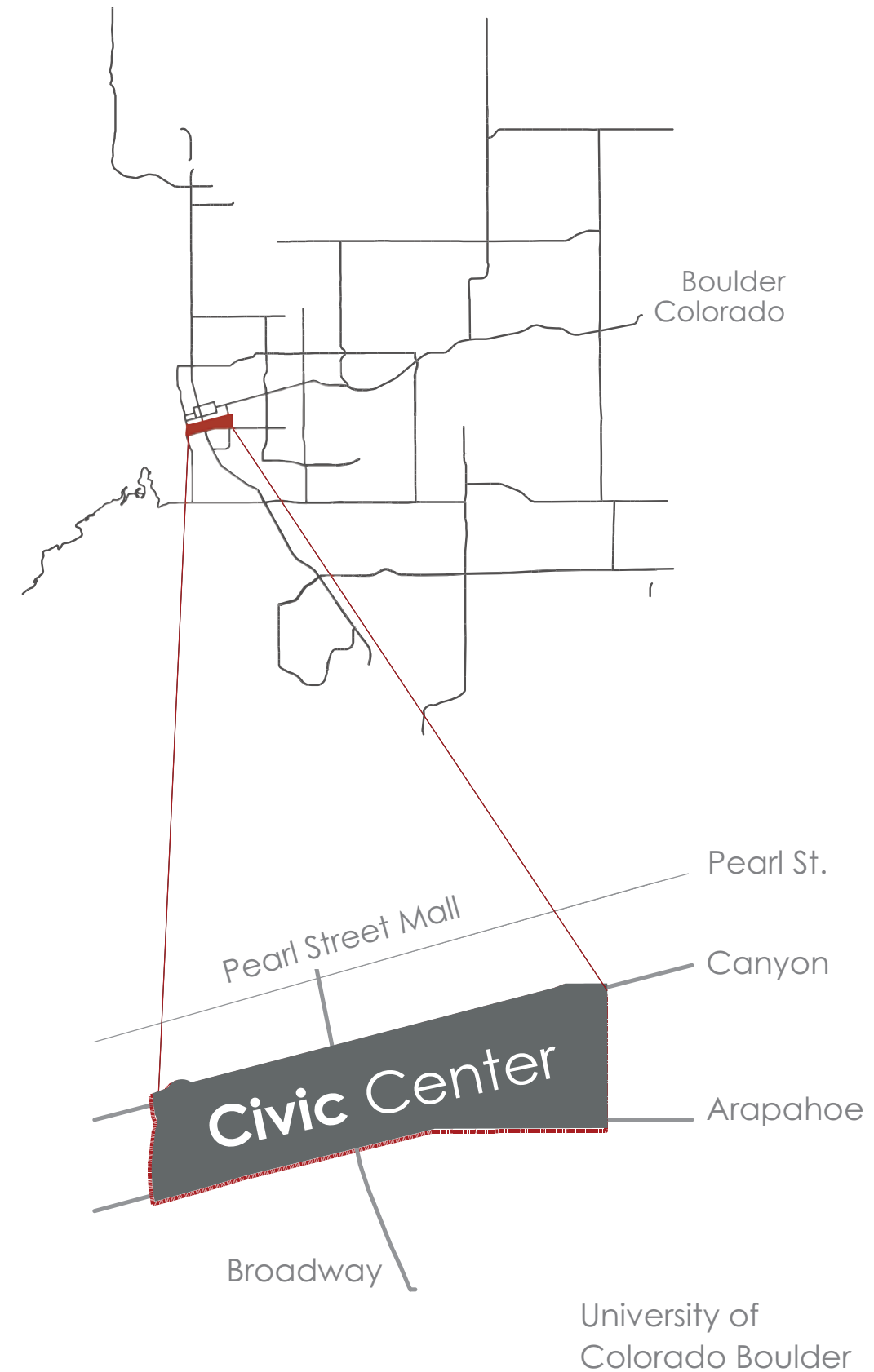


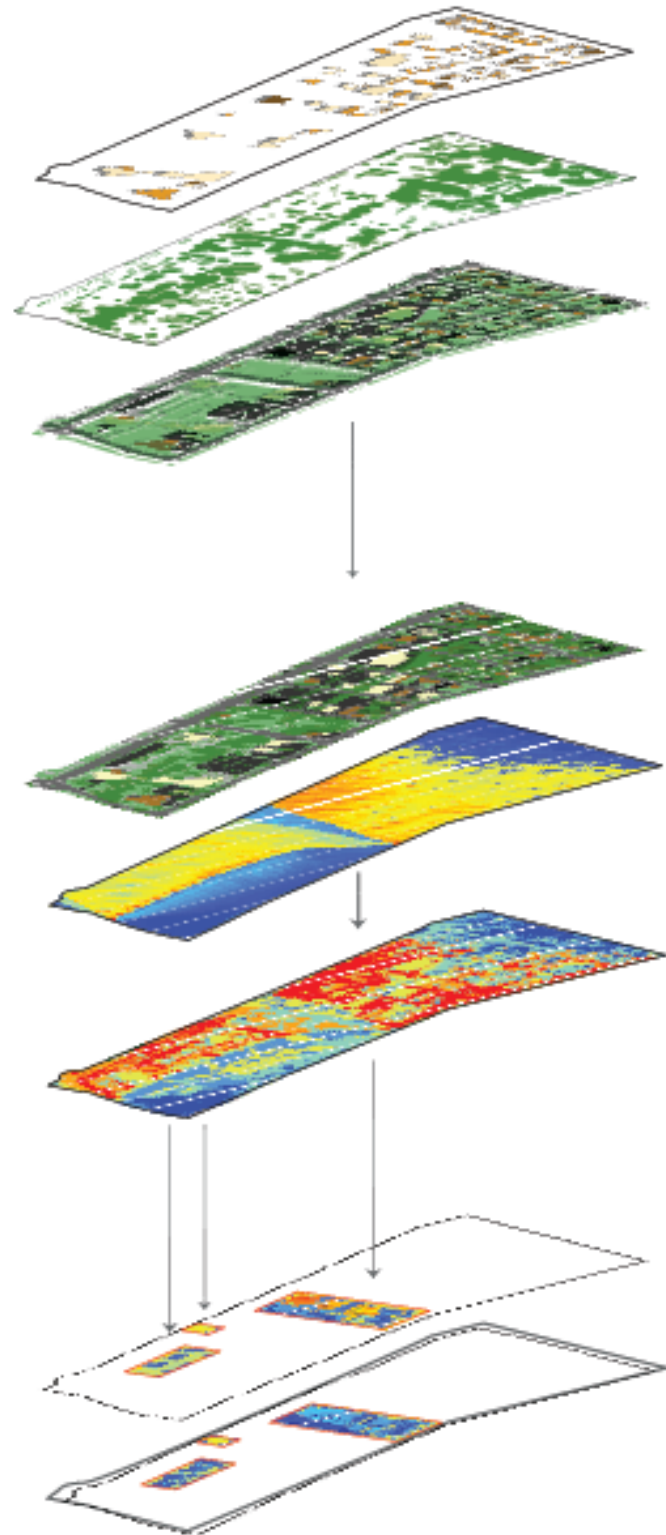
Project Intent

The project intent is to understand how the three urban features: urban form, green infrastructure, and surface materials, influence urban heat. By following the geodesign process and utilizing software such as ArcGIS, relationships between the built environment and urban heat can be conceptualized, modeled and tested. Three goals for the project are:

- 1 To create an inventory of the built environment by selecting specific features that influence surface heat.
- 2 To mitigate urban heat by exploring design strategies that optimize the relationships between features that influence urban heat.
3. To analyze the features inventory and identify areas where existing conditions create abnormally high or low heat.

As mentioned, the goal of this project is to help the City of Boulder identify sustainability indicators for urban heat and apply them within the context of the city's Civic Center Project. The Civic Center project is an important city initiative that involves the assessment of needs and development opportunities at a site defined by Arapahoe (south), Canyon (north), 9th Street (west), and 18th Street (east).





01 Inventory

Existing features that influence urban heat:

- Urban Form
- Green Infrastructure
- Surface Materials

02 Analysis

$$\begin{aligned} &\text{Weighted \% Heat Absorption} \\ &\text{of all features} \\ \times & \\ &\text{Solar Radiance} \\ = & \\ &\text{Relative Heat Map} \end{aligned}$$

03 Mitigation

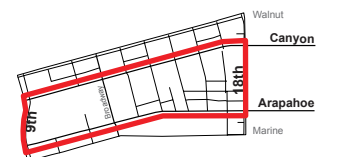
3 Scenario Typologies

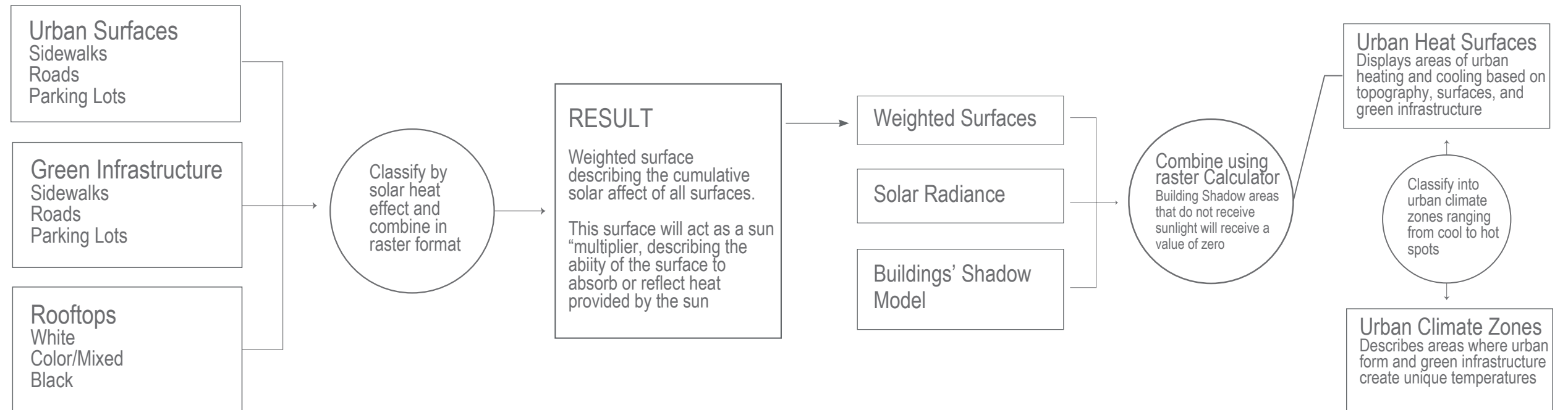
- Park
- Street Intersection
- High Development Potential (CFSA)

The Urban Heat indicator was developed by performing a weighted raster analysis using ArcGIS V.10 Spatial Analyst. Various features of Civic Center park were measured and represented in GIS shapefile format. These features included urban surface materials (roads, parking lots, and sidewalks) green infrastructure (ground vegetation and canopy), urban form (building roofs and shadows) and topography. Each surface was assigned a value describing its capacity to store heat. The method for assigning this value was derived by finding the albedo of each surface material and recording the inverse of the albedo to describe the percentage of heat that is stored by the surface material type. The inverse albedo describes an estimate of the surface material's capacity to absorb the heat that it receives from the Sun's radiance.

Surface data was collected largely from the city of Boulder's GIS database. Databases that were key to the urban heat indicator included; impervious surfaces and building footprints with heights. Other data included a 1/9 arc second Digital Elevation Model extracted from the USGS National Elevation Data set and the civic center tree canopy which was digitized from an aerial image by the urban heat student group. The DEM provided information about the topography of the site in order to perform a solar radiance analysis and estimate the intensity of sunlight reaching the surface of the Civic Center study area.

Urban form was analyzed using a 3D building shadow model developed by ESRI and modified slightly to fit this analysis. Building footprints were extruded to their heights and the building shapefile was converted to a multipatch file for a 3D analysis using ArcScene. ArcScene provides tools to estimate the Sun's position in the sky at a given time of day and year. The map of Sun's location can be used to perform a viewshed analysis against the 3D building multipatch file. Areas where the view from sun points were blocked were exported as a multipatch file and areas where the 3D shadow file intersect with the ground were converted to a shapefile and served to represent shadows generated by buildings.





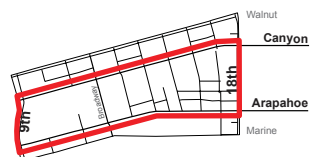
For this specific analysis, building shadows and solar radiance were projected for 12:00pm on June 20, 2012. This date was chosen because it is the summer solstice and was assumed to provide an example of the highest potential solar radiance. For future analysis, it would be valuable to perform shadow and solar radiance projections for several days in equal intervals throughout the year. This would allow for the identification of average solar radiance and shade locations throughout the entire study area.

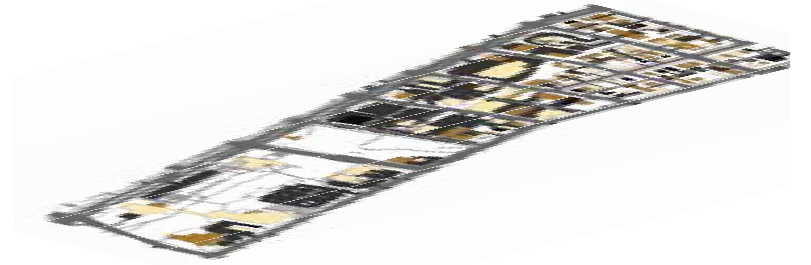
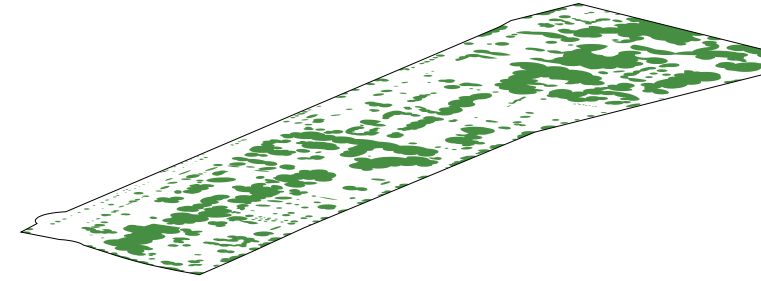
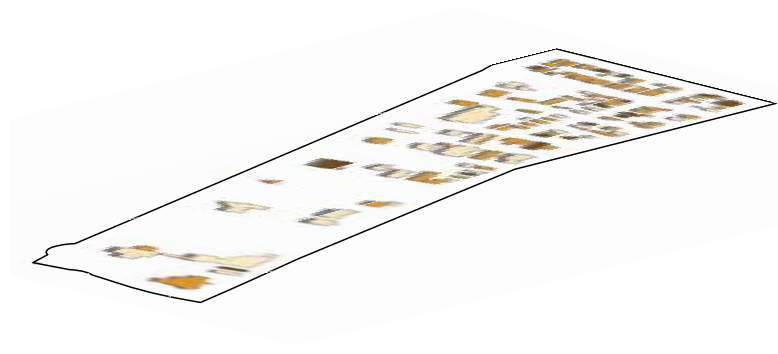
The output raster generated by solar radiance analysis describes the intensity of Sun in watts per square meter. This output raster was multiplied by the composite

of weighted rasters representing the capacity for each surface material type to retain heat from the Sun. The capacity for heat of each surface was represented on a scale from 0 to 100 in an attempt to describe the amount of heat stored as a percentage of the Sun's radiance value. The result of multiplying the solar radiance value by the weighted heat capacity raster was a new raster grid displaying areas with a range of projected heat values.

From the resulting raster output, the urban heat group was able to identify areas of concern where the projected heat values were abnormally high or low. These areas of concern were then used as case study areas to test the effects of different urban design and green

infrastructure mitigation strategies. The case studies chosen for this particular analysis included a portion of the civic center recreation area near the old library, the intersection of Broadway and Canyon, and the block of public property which contains the Dushanbe Tea House. These areas demonstrated abnormally high projected heat values and represent three types of design morphologies that can be applied to the site as a whole.





Urban Form

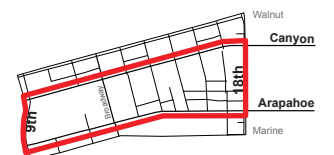
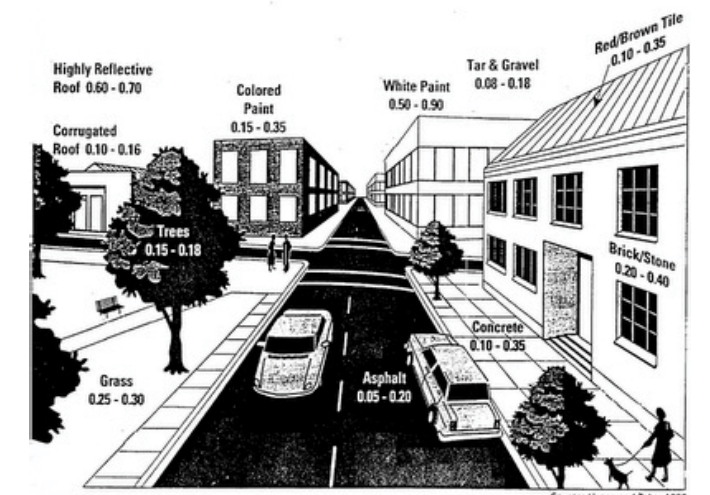
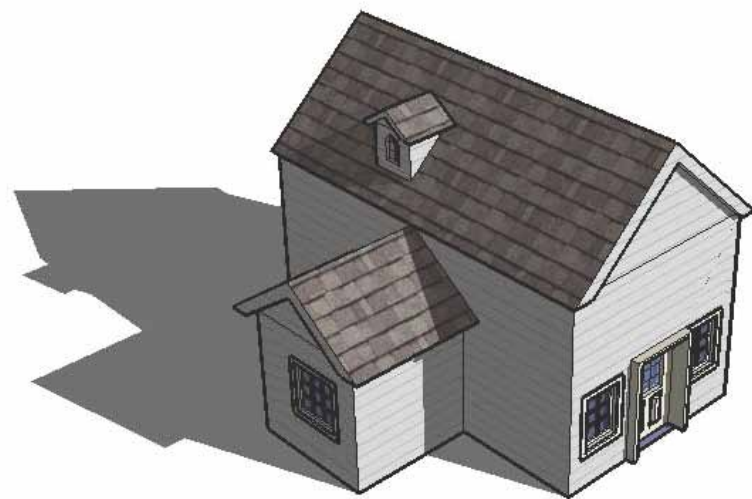
Urban Form refers to the physical arrangement and design of urban features. Building shadow and rooftop color are two elements of urban form that influence urban heat island.

Green Infrastructure

Green Infrastructure is a term used to describe strategic landscape and vegetation design. For this project, tree canopy is the main focus. Specifically, how tree canopy filters solar heat and reduces the amount of heat absorption of the surface materials.

Surface Materials



Surface Materials can be broken down into two categories: impervious surfaces and pervious surfaces. Impervious surfaces are typically man made surfaces such as asphalt and concrete and are located within streets, parking lots, and sidewalks. Pervious surfaces are usually natural surfaces, such as grass, that allow water absorption. According the EPA, pervious surfaces are usually cooler.







Urban Form

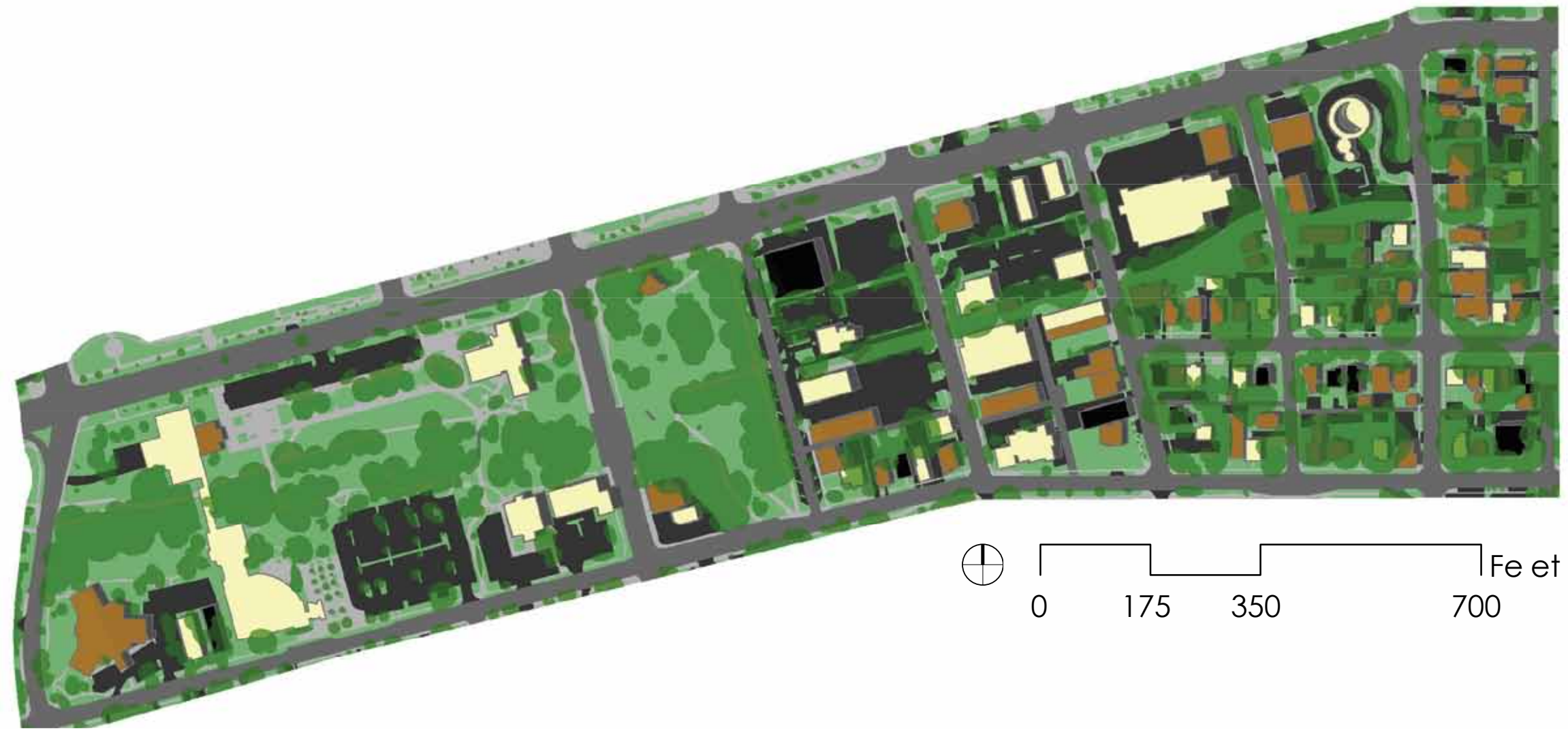
	White Roof	25
	Color Roof	50
	Black Roof	80
	Shadow	10

Green Infrastructure

	Summer Canopy	20
	Winter Canopy	60

Surface Material

	Road	75
	Parking	90
	Sidewalk	70
	Grass	60



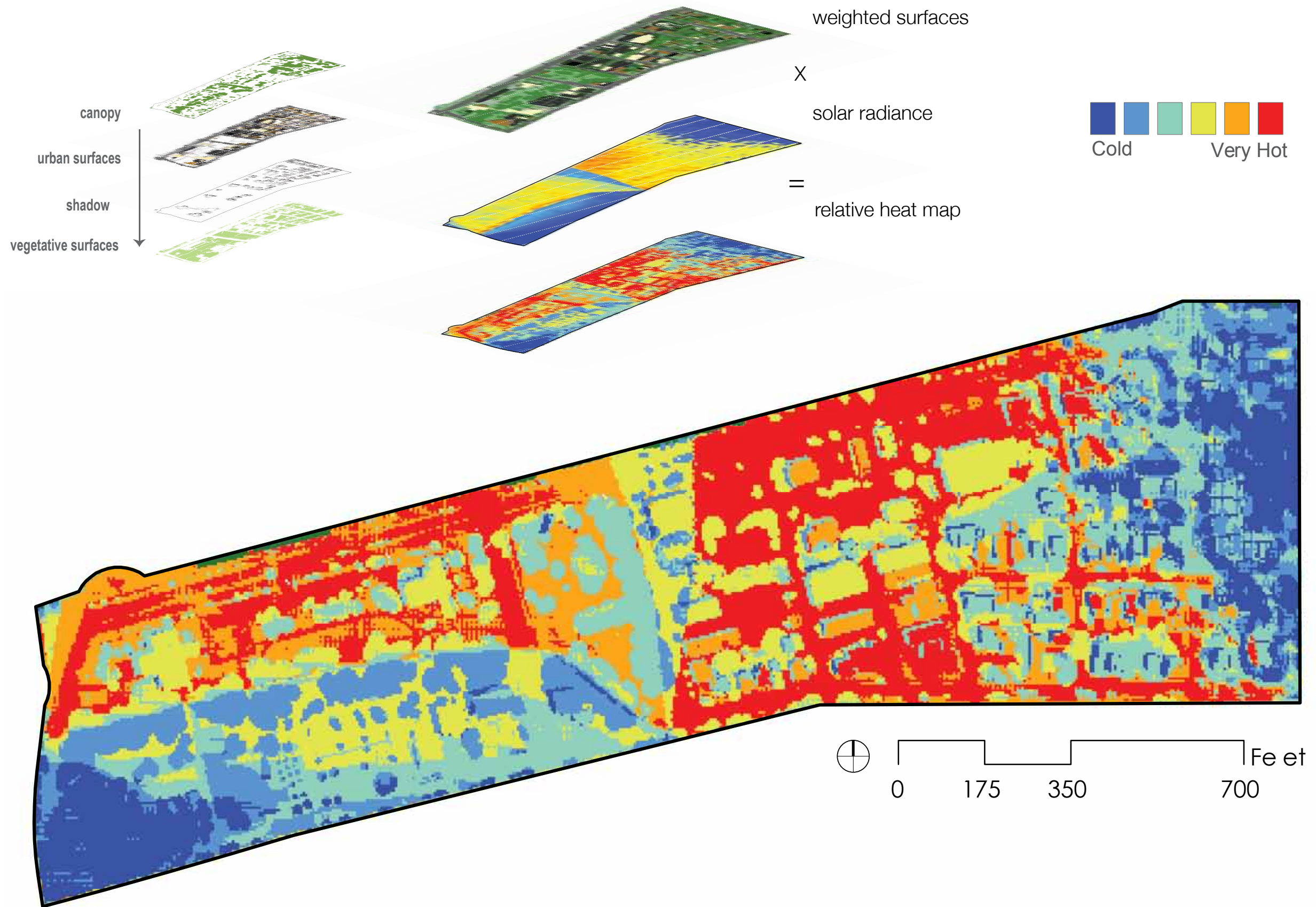
URBAN HEAT

Weighted Feature Map

SUSTAINABILITY ASSESSMENT PROJECT

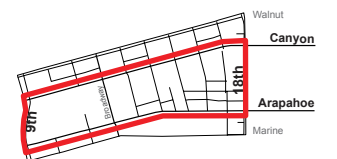
Density
Community Preference
Walkability
Stormwater

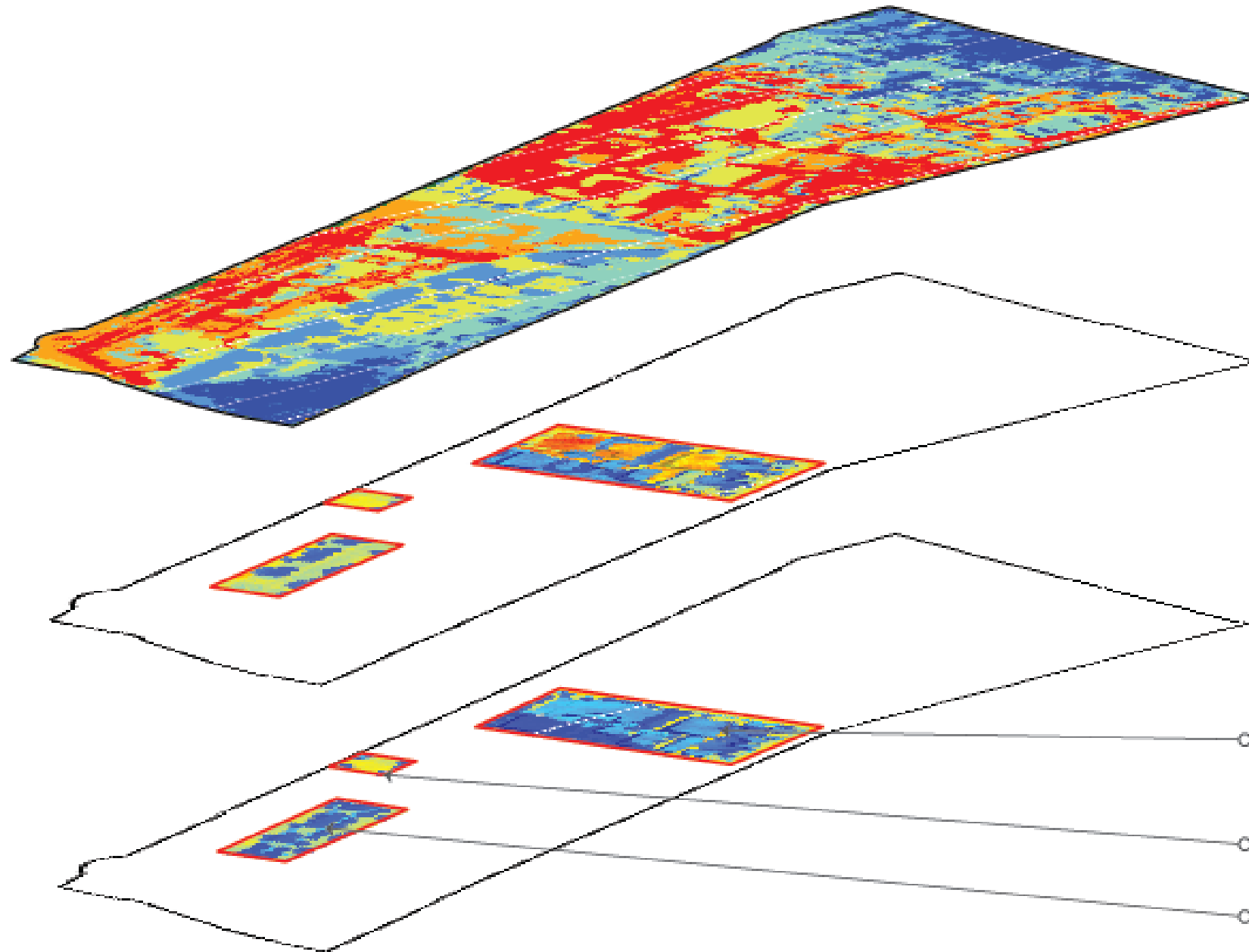
Urban Heat



URBAN HEAT

Analysis Relative Heat Map





Relative Heat Map

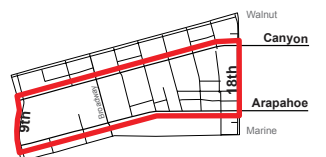
Priority Areas
for Mitigation

Scenario Typologies

- High Development Potential
Concentrated Focused Study Area (CFSA)
- Street Intersection
- Park

URBAN HEAT

Analysis to Mitigation



Scenario Typologies

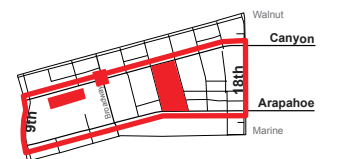
After creating a Relative Heat Map from the analysis of inventory features, three scenario typologies were chosen:

1. Park
2. Intersection
3. High Development Potential Area

Scenarios are presented as “typology packages” so that mitigation techniques and results can be applied or extrapolated across the Civic Center site and even throughout the City of Boulder.

Mitigation strategies that were chosen included adding additional canopy cover by planting deciduous trees, changing rooftop material, and resurfacing impervious surfaces. Impervious urban surfaces such as asphalt parking lots, concrete streets and sidewalks were projected to have been resurfaced by the most effective high albedo material as defined by the EPA. Each scenario contained the most advanced mitigation strategies defined by a quick review of literature. Resurfacing of entire impervious urban surface areas were projected without regard to cost or implementation feasibility.

Results were analyzed based on the average projected heat value for all cells within each case study. The product of multiplying the solar radiance raster by the weighted surface raster was expressed in the unit Watt per meter squared. This number was converted to the British Thermal Unit (BTU) to be more manageable and easily interpreted. The mean heat in BTU's were compared for before and after the implementing the urban heat mitigation strategy. This comparison results in a percentage lost in heat projected for each case study area as well as for the study area as a whole.



Intervention

75% Increase in Vegetation

100% Asphalt Converted to Improved Asphalt

Heat Results

24 BTU Before Mitigation

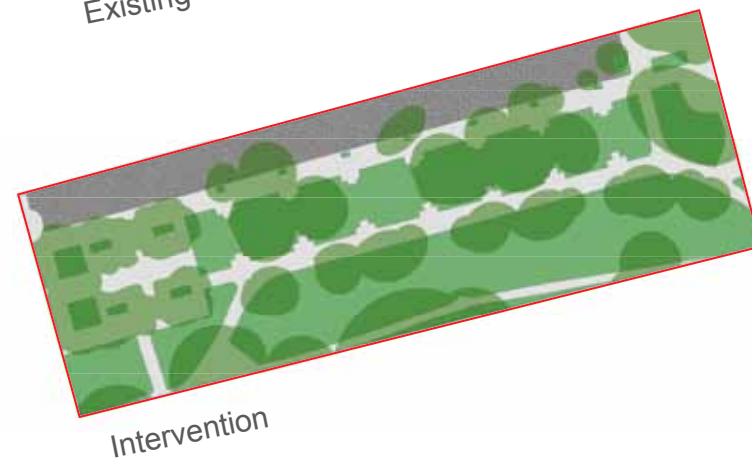
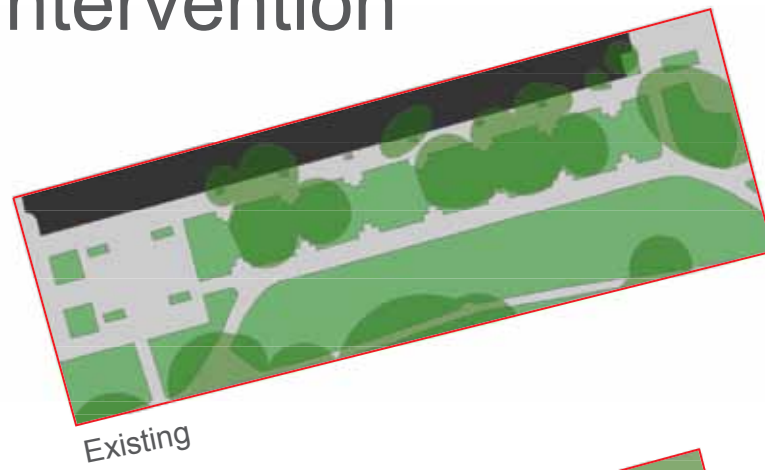
15 BTU After Mitigation

**35 % Decrease in
Average Heat**

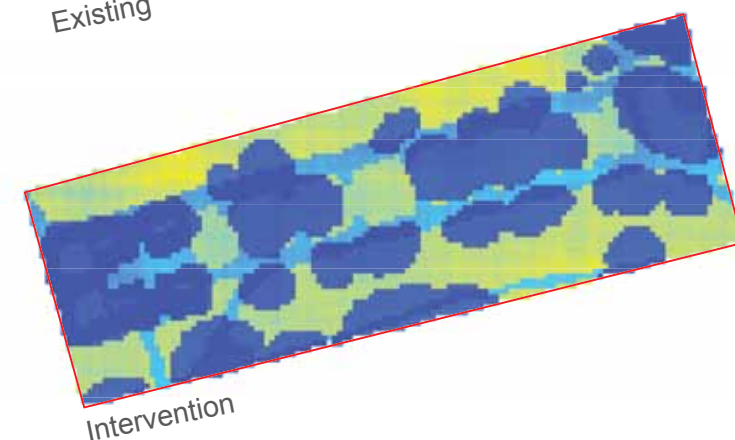
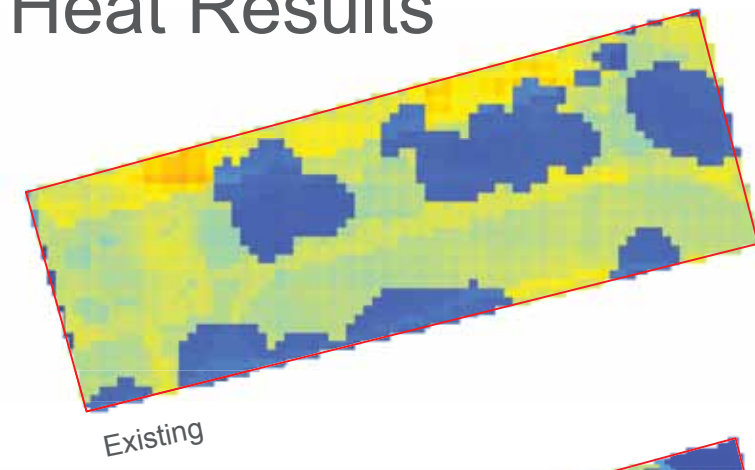
Parks are important elements within an urban landscape for many reasons, especially for mitigating urban heat. The park typology scenario focuses on a section of the park by the Boulder Public Library near Canyon and Broadway.

According to the “EPA Reducing Urban Heat Island Compendium of Strategies” resource, increasing tree canopy is an effective strategy to cool areas. As shown by the table to the right, by increasing canopy 75 percent and converting 100 percent of the asphalt to an improved asphalt, the average heat decreases by 35 percent.

Intervention



Heat Results



Intervention

88% Increase in Canopy
38% Increase in Vegetation

100% Asphalt Converted to
Improved Asphalt

100% Sidewalk Converted to
Improved Concrete

Heat Results

32 BTU Before Mitigation

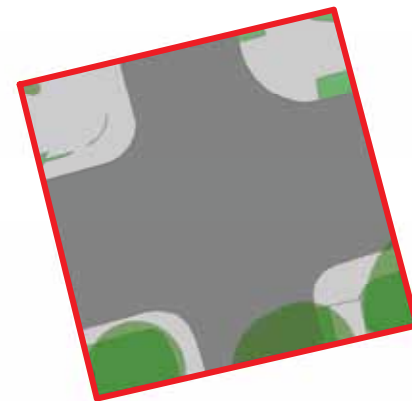
27 BTU After Mitigation

**18% Decrease in
Average Heat**

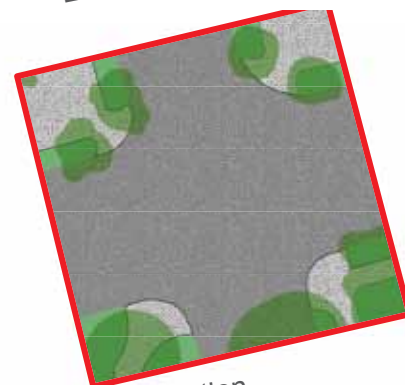
With the extensive use of asphalt for street surfaces, intersections can be considered high priority areas for mitigating heat. The intersection chosen for the scenario is Broadway and Canyon, which are two major streets in Boulder.

As shown by the graphics and table, by increasing canopy by 88 percent, vegetation by 38 percent, and changing 100 percent of the asphalt and sidewalks to cooler pavements, the average heat decreases by 18 percent.

Intervention

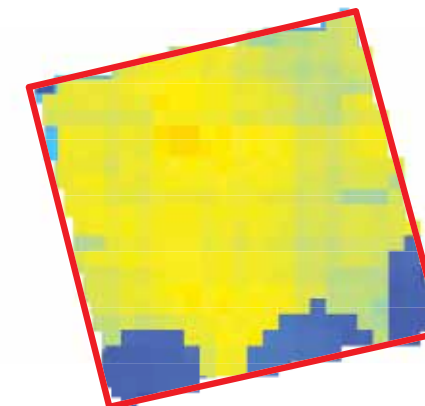


Existing

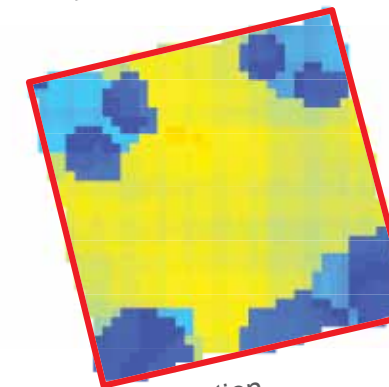


Intervention

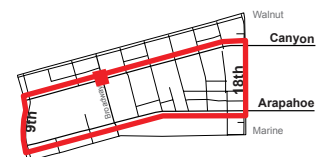
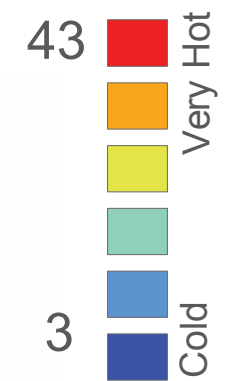
Heat Results



Existing



Intervention



**SUSTAINABILITY
ASSESSMENT PROJECT**

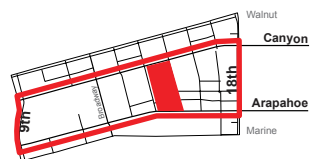
Density
Community Preference
Walkability
Stormwater

Urban Heat



URBAN HEAT

High Development Potential Scenario



Intervention

223% Increase in Bldg Footprint
570% Increase in Shaded Area
12% Increase in Canopy
10% Increase in Vegetation
330% Asphalt Converted to Improved Asphalt
58% Decrease in Road and Parking Area

Heat Results

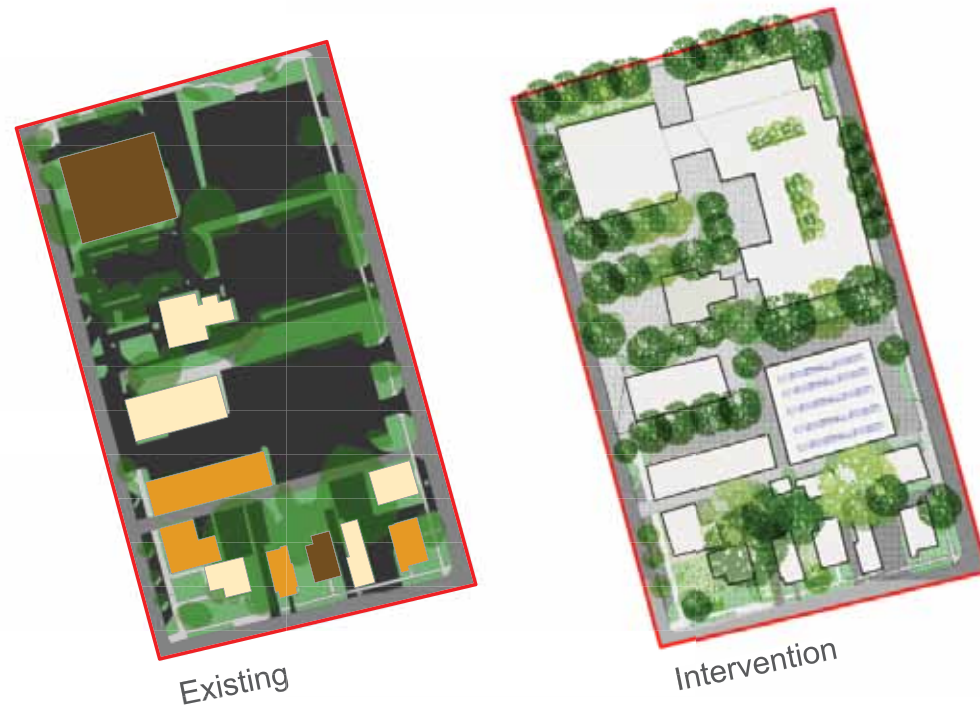
29 BTU Before Mitigation
24 BTU After Mitigation

**21% Decrease in
Average Heat**

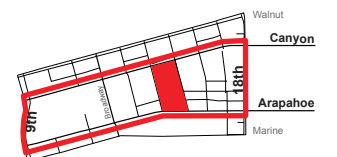
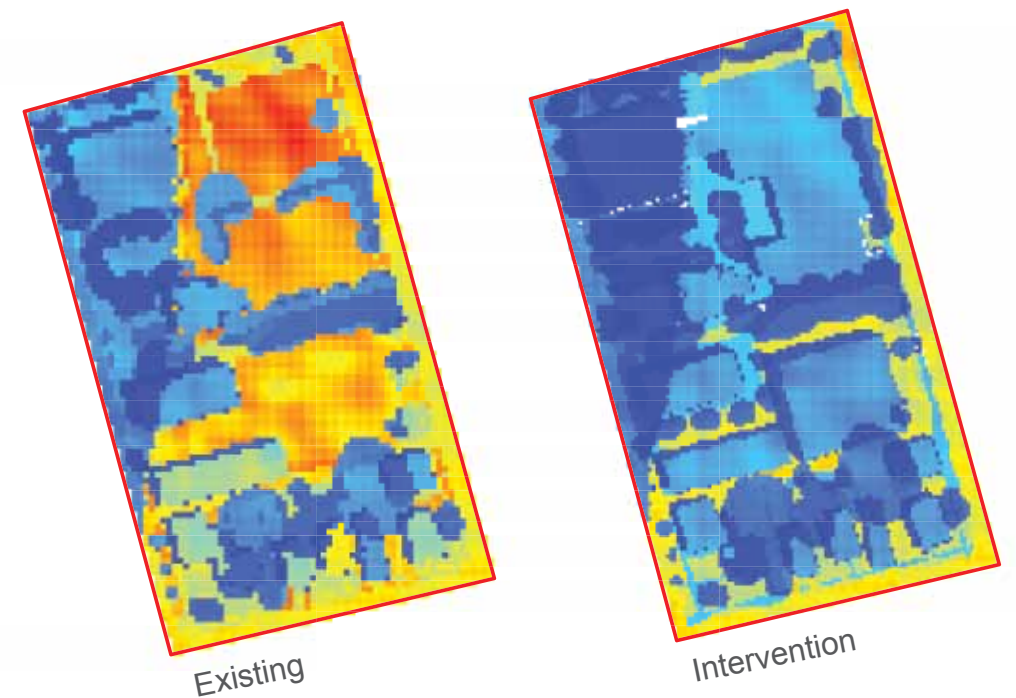
Compared to the Pearl Street Mall, just two blocks north of Canyon, the Civic Center has several under-utilized parcels and wide open parking lots. One of these areas is located between 13th and 14th street and stretches all the way from Arapahoe to Canyon.

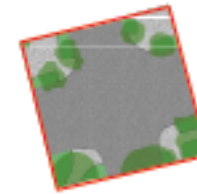
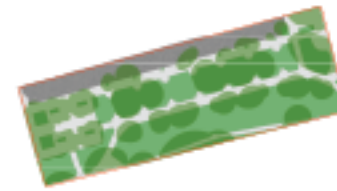
In this extreme scenario, several design considerations are explored to mitigate urban heat. A new building is constructed that replaces the old parking lots, a parking garage maintains the number of parking spaces and houses solar panel carports on the rooftop, and canopy is used to shade public spaces. As a result, average heat decreases by 21 percent.

Intervention

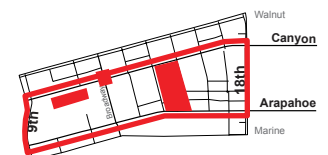


Heat Results





	Park	Intersection	CFSA
Urban Form	No Change	No Change	223% Increase in Building Footprint 570% Increase in Shaded Area
Green Infrastructure	75% Increase in Canopy	88% Increase in Canopy 38% Increase in Vegetation	12% Increase in Canopy 10% Increase in Vegetation
Surface Materials	100% Asphalt Converted to Improved Asphalt (25,808 sq. ft.)	100% Asphalt Converted to Improved Asphalt (12,661 sq. ft.) 100% Sidewalk Converted to Improved Concrete (3,474 sq. ft.)	58% Decrease in Road/Parking Surfaces (92% Improved Surface) 330% Increase in Sidewalk Surfaces (63% Improved Vehicle Surface)
AVERAGE HEAT	38% Decrease	18% Decrease	21% Decrease



Conclusions

By utilizing the geodesign process, an urban heat model was conceptualized, modeled, and tested. Through analysis of the three urban features: urban form, green infrastructure, and surfaces materials, a Relative Heat Map was generated, which identifies areas of concern with either abnormally high or low heat. From these areas of concern, three scenario typologies were chosen: park, intersection, and high development potential. Mitigation strategies, recommended by the EPA, were employed to each scenario: adding additional canopy cover, changing rooftop material (color), and resurfacing impervious surfaces. After the new designs were run through the Urban Heat Model, a change in average heat was calculated. From the results, it is clear that the mitigations chosen do in fact help reduce surface heat.

Other important findings are:

1. By taking inventory of the built and natural environment, it is possible to estimate areas with abnormally high or low heat.
2. The accuracy of analysis is dependent on the richness of the data describing the built environment.
3. Developing urban heat mitigations require both quantitative and qualitative analysis of the site.

Upon creation and review of the urban heat analysis it was determined that certain areas within the civic center study area do consist of features that are likely to absorb abnormally high amounts of heat from the Sun's radiation. After a visual review of the projected heat surface, three areas were selected as scenario case studies. Heat mitigation strategies were input into the GIS data through digitizing and changing heat absorption values. The modified data was then re-entered into the urban heat indicator model and review to identify changes in the average projected heat, measured in BTU. The mitigation strategies as well as the resulting heat values are displayed in the table above.

The Urban Heat Indicator is an attempt to respond to a section of the Boulder Valley Comprehensive plan which defines sustainable urban form in the context of the planning and design of the city of Boulder. The definition of sustainable urban form is divided into components which include; compact, connected, complete, inclusive and green, attractive, and distinct. The Urban Heat Indicator is designed to perform analysis within the green, attractive and distinct component. The definition of green, attractive and distinct ensures the "location and design of buildings, streets, utilities and other infrastructure to protect natural systems, minimize pollution and urban heat island effects and support clean energy generation." (BVCP update 2010)

The Urban Heat Indicator is intended to identify the relationship between features of urban form, urban surfaces, green infrastructure and natural systems as they react to the natural energy produced by the Sun. Through performance and modification of the Urban Heat Indicator, patterns of understanding will emerge that will enable urban planners and designers to make informed decisions when trying to create public places that satisfy the objectives described by the green, attractive and distinct component of sustainable urban form

References

- Artz, Matt. "Changing Geography by Design" <http://www.esri.com/library/ebooks/geodesign.pdf>. Oct. 2010.
- Bretz, Akbari, Rosenfeld, and Taha. "Implementation of Solar-Reflective Surfaces: Materials and Utility Programs". University of California. June 1992.
- EPA "Reducing Urban Heat Island Compendium of Strategies". <http://www.epa.gov/heatis-ld/resources/compendium.htm>. 2008.
Trees and Vegetation
Cool Roofs
Cool Pavements

