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Firesafe: Designing for Fire-Resilient Communities in the American West

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FIRESAFE: DESIGNING FOR FIRE-RESILIENT COMMUNITIES IN THE AMERICAN WEST

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FIRESAFE: DESIGNING FOR FIRE-RESILIENT COMMUNITIES IN THE AMERICAN WEST

A Thesis Proposal

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DEDICATION

For my daughter Toni, my wife Anya, and the resilient people of the American West.

“Your own property is concerned when your neighbor's house is on fire.”

- Horace

ABSTRACT

FIRESAFE: DESIGNING FOR FIRE-RESILIENT COMMUNITIES IN THE AMERICAN WEST

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The perception that wildfires are completely preventable has caused many structures and communities to be built in locations that will inevitably experience an uncontrollable fire event, risking human lives and infrastructure. Modification of built environments into fire-adapted communities has been explored in this thesis, through multiple strategies. Central to this analysis is the idea that sustainable human developments could adopt a form of biomimicry and indigenous design informed by the adaptions of plants, animals, and native groups that endure and even thrive with regular cycles of fire. This possibility has been assessed through the scope of fire adaptation strategies available to architects, builders, and urban planners. Design decisions including the strategic placement of buildings in relation to topography, wind, vegetation type, and fuel loads has been considered. Additionally, other mechanisms for adaptation have been assessed, such as fire-retardant building materials, building form, landscaping, and the density of built form on the scale of single homes, and broader communities. The thesis identifies a typical building site, the adjacent community, the potential threats to landscape and buildings posed by wildfire, and then explores design approaches aimed at improving fire adaptability. These factors have been considered and assessed on a qualitative level and

offer new recommendations for building within fire zones. These design ideas and principles can then be applied to a variety of landscapes wherein the wildfire is inevitable, thereby exploring how fire-adapted communities may be built to sustain wildfires through a myriad of methods within a range of regions.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

According to "The 2019 Wildfire Risk Report," the United States has "776,000 homes with an associated reconstruction cost value of more than $221 billion at extreme risk of wildfire damage." (Jeffery et al., 2019, 1) With such massive numbers suggesting unknowable risks, one may see this warning as sensationalism and shirk. Such attitudes were commonplace for decades, as wildfires flared up in seemingly isolated contexts and were quickly extinguished. Yet, in recent years, fire seasons in the U.S. have begun in singular locations, only to spread, connect to other conflagrations, and be joined in the headlines by massive fires elsewhere, these events often burning more acreage and last far longer than historically seen (Russell, 2019). The causes for this acceleration are debated as people attempt to understand, deny, or bargain themselves out of a growing threat. Yet outside of burn bans, suppression by firefighters, and interventions made by individual property owners, little has been done to prevent such conflagrations (Kasler & Reese, 2019).

A relatively recent surge of human settlement of areas in the American West in landscapes that have evolved with fire has combined with an influx of property owners originating from places foreign to the concept of fire-dependent ecosystems (Paveglio et al., 2019, 4). The natural impulse has been to create buildings and communities that ignore the inevitable. As climate change causes temperatures to rise and weather patterns to become less predictable, this risk is increasing exponentially, while many property owners continue to build structures and maintain yards that welcome wildfire, furthering the likelihood of destruction. Indeed, the rise of wildfire incidence within the U.S. and abroad has resulted in a massive loss of life and the destruction of entire communities, prompting questions of how architecture and urban design might be used to shape fire-adapted communities situated within fire-dependent ecosystems.

But what if the residents of these places began to build for resilience? What if structures and communities were designed in such a way that wildfire is seen as an essential function of the place a rather than a liability, as with monsoons in tropical climates**?** Just as plants and animals have evolved to weather the natural cycles of destruction and regrowth, so might humans learn to adapt to these environments. Given the need for new ways to prevent loss of life and property, planners, architects, and builders must ask how design thinking might be used to shape the fire-adapted communities of the American West within the context of fire-dependent ecosystems.

An initial exploration of the resources available to those seeking to make properties and communities more fire-resilient indicates that there are many examples of materials and approaches that may minimize risk while increasing ecologic health. Still, so misunderstood are the means and methods of fire-preparedness that many people see wildfire as, "a unique peril because the level of damage is often binary – a home is either left untouched by the fire or a total loss occurs." (Jeffery et al., 2019, 5) Research into the behavior and movement of these events suggests that destruction by wildfire may not be random (Kasler & Reese, 2019). Through an assessment of existing methods and policies in place within relevant communities in the American West, many lessons can be learned from the range of building materials; overall community design models; lessons offered by biomimicry; as well as methods of fire-management used by indigenous communities. From this information one may synthesize a plan for both structural and community designs that better prepare people for the uncertainty of wildfire, so that the seemingly erratic behavior of fire may be anticipated and accepted rather than feared. These design ideas and principles can then be applied to a variety of landscapes wherein the wildfire is inevitable, thereby exploring how fire-adapted communities may be built to sustain wildfires through a myriad of methods.

Based on an analysis of existing literature, methods, materials, and planning arrangements, properties and communities may be designed to withstand wildfire and prosper in fire-dependent ecosystems. Taking lessons from nature and indigenous practices, structures may be adapted to fire by following three primary strategies: fireproofing with fire-resistant building materials; adaptation based on the habits of burrowing animals faced with the threat of flames, as well as the securing of perimeters with defensible space and buffers of water, stone, and greenspace. Each structure may hypothetically be employed in multiple ecosystems with varied fuel loads, slopes, and orientations. Beyond individual structures and properties, the design and policies of communities located within fire-prone locations may be better protected and prepared for the inevitable. Combined, these findings will serve as a model for structural, landscape, and community-scaled methods of resilience in the face of wildfire as informed by conventional practices, as well as novel ideas gleaned from principles of biomimicry and indigenous practices.

CHAPTER 2

LITERATURE REVIEW

Introduction

While uncontrollable fires have recently gained a great deal of attention in news and media, the history of civilization has been marked by their effects as historic infernos consumed entire communities. Stories of great fires have become mythologized, be it Rome burning as Emperor Nero fiddled, or the cow that allegedly kicked over an oil lamp and caused the Great Chicago Fire. What separates these incidents from wildfires is the fact that they resulted in policy changes such as new building forms or materials, and there were obvious ways to avoid them. Unlike such urban-centered fires, the damage caused by wildfire is largely unavoidable - or is it? In a comprehensive analysis of research and media related to wildfire and how humans inhabit fire-dependent ecosystems, there are a myriad of issues that may contribute to the discourse on how communities may best adapt to become more resilient to the effects of wildfire. This literature review begins by defining the conventions of fire-resilient communities ranging from building materials to overall community design. Then, an analysis is made of the possible lessons offered by biomimicry of organisms that are well-adapted to such conflagrations. This is followed by an exploration of methods of fire-management that have been long-practiced by indigenous communities in the U.S. and beyond. From this discourse a clearer understanding will be gained of how these ideas and designs may be used to shape fire-adapted communities of the American West within the context of fire-dependent ecosystems.

Current Conventions in Fire-Resilience

While the idea of adopting strategies for fire prevention may seem novel, the practice has been in place for centuries. It truly gained mass appeal with the advent of skyscrapers, incited by the perception that such towering columns could create catastrophic infernos if they were to catch alight. This is outlined in Eleanor Cummins' article, "Fire-Proofing California's Homes Is Possible-but at What Cost?" (Cummins, 2019) As skyscrapers became more widespread, so did building codes and restrictions, as the perception of danger and risk increased. While this is the logical progression for adaptive design and policy, the process has been less successful in places where wildfires are most likely to occur. Often these locations are rural places of isolation where rules are hard to enforce, and personal freedom is held at a premium. Further exacerbating the situation is a changing climate, in which periods of drought and high winds are fanning high loads of forest debris and brush that have resulted from decades of total fire suppression carried out by local and federal governments (Westervelt, 2019). With Smokey Bear as a mascot, the U.S. Forest service has campaigned against forest fires so successfully that many fire-dependent ecosystems are now less healthy due to a lack of cyclical fire events (Smith, Kolden & Bowman, 2018). With people inhabiting these areas more often, the risk compounds as structures and people are placed in harm's way. Many of these structures are arranged in a suburban style, with sprawling lots, treed yards, wooden fences, landscaping leading right up to walls and rooftops made of materials chosen for aesthetics rather than fire-resistance. Commonly referred to as 'wildland-urban interface,' this is the type of community most likely to burn in the event of fire, and yet zoning designations have encouraged building in such places as nearly half of the new homes built in America today are built within this interface of sprawl and heavy vegetative fuel loads (Westervelt, 2019).

The Single Property Approach

In many such places there have been advances in the adoption of design implements aimed at increasing fire resilience, as many parts of the American West have embraced strategies such as defensible space (a non-combustible perimeter), stricter residential building codes, along with fire retardant materials and styles of Spanish and Southwest architecture that use stucco facades and terra cotta roof tiles (Cummins, 2019). In terms of defensible space, popular approaches call for a one-hundred-foot perimeter in which property owners eliminate brush and combustible plants; utilize fire retardant groundcover like sedum, well-watered grass, or gravel; and limit or trim trees with consideration for proximity to rooflines (Westervelt, 2019).

Beyond such measures, there is a wide variety of popular materials that may withstand embers and direct flame. Fire-resistant building applications include stone, concrete, or composite decking; stucco, brick, or concrete composite siding; metal-framed windows; and terracotta, concrete, or metal roofing (Ibid.). But the use of fire retardant material is often limited by costs, as such measures are often prohibitively expensive. In fire-prone California, measures to incentivize retrofits for earthquake readiness have long been in place, yet while there have been talks of incentivizing the retrofitting of existing structures to include fire-retardant materials, they have yet to happen (Ibid.). And, while California may have the strictest standards of fire protective building code for structures built after 2008, they leave much room for improvement as older structures remain vulnerable and stand ready to spread the flames in the event of fire, as in Paradise (a California community destroyed by fire in 2019), where "just 18% of homes built before 2008 survived the blaze." (Ibid., 14) Perhaps the easiest way to address long-term fire risk is to mandate structural retrofits and defensible space in certain areas.

Comprehensive Community Fire Resilience

While improved architectural and site-specific measures may help to protect some properties, comprehensive measures have been few. Indeed, even fire-resistant building materials can be at great risk when placed in proximity to an older structure that catches on fire, as fire resilience may rely on community design as much as smart architecture (Cummins, 2019). The risk of structural loss is so great that some community leaders may suggest rezoning to reduce total buildable areas based on likelihood of fire. In Paradise, California, proposals have been made for sections of the sprawling town to be left vacant after wildfire consumed much of the area, with ideas proposed for government buyouts that would remove private land from the public market as people are removed from harm's way, creating defensible space on a broad scale as land is made into a buffer of recreational green space (Westervelt, 2019). Though many experts hail such policies as a valuable step toward long-term wildfire mitigation, doubts remain as a history riddled with ideas of manifest destiny and the pioneering spirit have many in the American West convinced that people can tame nature and suppress such events. In his article "After Paradise, Living with Fire Means Redefining Resilience," Eric Westervelt calls it "an ethos baked into the federal disaster response system, what critics call the "disaster industrial complex" — a system constructed around responding to natural disasters, delivering immediate and long-term aid." (Ibid., 3) Indeed, such policies are based in politics rather than fire policy as few elected officials would expect reelection after deeming large portions of a municipality.

In some towns and cities, limited strategies of fire resilience have been implemented with some success as people learn from recent events. In Paradise, California, one such enactment is the repair of a long-neglected emergency alert system of sirens used to alarm residents of approaching fire after such alerts failed to notify the public via telephone and television notifications failed to properly warn the public even as homes burned and lives were lost (Ibid.). Other measures include conventional methods such as defensible space, along with unconventional ideas like the deployment of herds of goats that are grazed with the aid of GPS monitoring used to reduce fuel loads in areas thick with brush or on hillsides too steep to clear by hand (Ibid.). Much like the practices of indigenous people long-adapted to fire-prone ecosystems, such methods are a step toward an approach based on natural cycles.

In the California town of Truckee, municipal authorities have gone a step further as they maintain a perimeter of clearings and thinned forest around the alpine town, effectively creating a firebreak. Other policy changes include seasonal bans on barbecues and campfires (even as the area remains a major destination for outdoor recreation), prescribed burns, as well as a defensible space inspection required with every real estate transaction, and comprehensive plans for response and evacuation in the case of wildfire (Ibid.). Such measures are a logical step as many fires are accidentally started by careless actions simple as flicking a lit cigarette from a car window.

Indeed, the element that remains the least controllable is individual behavior, as people are often slow to respond or outright defiant in the face of authoritarian mandate.

Education remains an issue as many residents in fire-prone areas remain without a plan for defense, communication in the event of an emergency, evacuation procedures, or day to day fire conditions (Ibid.). Indeed, one essential point made by Westervelt is that "There needs to be wholesale mindset change about wildfire in the West… by everyone — homeowners, planners, builders and policymakers." (Ibid., 17)

Yet the desire to ignore the lessons of recent disasters and rebuild a community as it was before a wildfire is a natural impulse that can easily result in repeated cycles of destruction. While every community is different, incentives, strict building codes, and regular inspections could result in a reduced likelihood of individual loss. On a broader basis, the powers of local, state, and federal government could finance such measures while also mandating land use changes aimed at improving the performance of entire communities facing the threat of wildfire. Without such comprehensive safety measures there remains little doubt that communities in the wildland-urban interface will continue to suffer widescale destruction due to increasingly frequent and unpredictable fire events.

The Role of Biomimicry in Fire-Adaptation

In modern western thought, wildfire has been framed by polarized notions of fire's role in nature, wherein, "Ecologists used to believe nature evolved to create pristine ecosystems of climax vegetation… They saw fire as a ruinous interruption to that evolution. But we can now see that fire has a major biological role. It shakes and bakes. It frees nutrients and restructures biotas – it takes apart what photosynthesis puts together," (Pearce, 2015, 144). Embracing this belief that fire plays an essential biological role, designers may observe and adopt various aspects of nature's wildfire adaptation systems. The result may be a systematic series of design interventions informed by biomimicry.

The term biomimicry has gained tremendous attention in the past two decades as designers and scientists look to nature for solutions to complex problems, as described by the Biomimicry Institute: "Biomimicry is a practice that learns from and mimics the strategies found in nature to solve human design challenges" (Benyus, 2021). Indeed, some researchers have already proposed the implementation of adaptive strategies employed by the plants and animals that have evolved to inhabit fire-dependent ecosystems. In one research article entitled "Biomimicry Can Help Humans to Coexist Sustainably with Fire," the authors postulate that, "collaborations between urban planners, architects, engineers and ecologists should adopt the principles of biomimicry and follow the lead of organisms and indigenous peoples that have evolved to thrive in flammable environments." (Smith et al., 2018, 1827) Presented in their findings is an assessment of the four primary ways that organisms react to wildfire. According to this source, this is related to how the built environment reacts by either remaining sensitive to fire and burning; by avoiding fire events as much as possible; by adapting form as with trees with fireproof bark; and finally, through dependence wherein fire kills competition but aids biological processes, as with seeds that only germinate after heat exposure (Ibid.).

Of these four responses to fire, the least opportune is a sensitivity to fire that results in burning, and yet that seems to be the more common response of structures and communities faced with regular cycles of wildfire. An obviously superior approach would be fire avoidance, adaptation, or even fire-dependence. Without such measures, the cycle of fire, destruction, and rebuilding will prove too costly in relation to finances, resources, emotional trauma, and human life. In looking at the strategies employed in nature, Smith et al. propose that biomimicry offers solutions that will allow humans to coexist with fire indefinitely (2018).

The first of these fire-adaptive options is avoidance, whereby humans may mimic the behavior of animals that flee to a safe place, and plants may react by storing energy and nutrients in their root systems, or within fire-adapted foliage held high in their branches (Ibid.). These principles can be related to structures in which the inhabitants build walls, build fire-retardant elevated structures that allow ground fires to pass them from below, or by constructing semi-subterranean homes or a single underground room that operates much like an insulative burrow (Koksal, McLennan, Every, Bearman, 2019). In some cases, animal burrows act as fire-adaptive strategies that shelter beyond the builder, as with Australian wombat burrows wherein, "countless small animals have escaped death because wombats, unusually, opted to share their massive complex burrows," in acts of tolerance in times of disaster (Dupuy, 2020, 2).

While the burrowing of structural form is novel to modern humans, such structures were common in ancient times and the insulative qualities of soil remain relevant as communities in hilly, arid areas with lower fuel loads and less likelihood of sustained smoke inhalation could promote subterranean homes as a safe way to avoid wildfire (Smith et al., 2018). In some municipalities, this approach is already employed with essential services such as plumbing and electrical lines. Additionally, the same principle could be employed through the elevation of structures on stilts, with undersides clad in fire-resistant materials, "where fire is directed… in the same manner that a storm drain directs flood water away from communities… where engineers could learn from topographic and atmospheric processes to encourage inversions to keep smoke away from the elevated platforms." (Ibid., 1829) Although most building codes and conventional building practices could restrict the application of such methods, they should be fully considered as viable means of fire avoidance as humans are forced to reconsider their place in fire-dependent ecosystems.

Another option is that of adaption, as with fire-adapted plants that drop lower limbs so that a typical brushfire can't climb their branches. Or, in a highly specialized case, Hawaiian ʻŌhiʻa lehua trees have adapted to colonize a volcanic landscape of lava flows where, "stomata (pores in leaves that allow plants to breathe)… will close up in the presence of harmful gases, when many non-native trees will struggle or die back" (Trees, 2020, 2). Such adaptations are like protected vents and apertures which block embers and may seal completely via mechanical means when fire nears. Additionally, within redwoods and other species, thoroughly insulated fireproof bark allows flames to pass without hindering the trees' essential functions, as is similarly seen in fire-resistant cladding, roofing, and internal structural materials.

Beyond the scope of building form and material, building sites may be informed by biomimicry of Mediterranean Cypress – a tree species that retains high concentrations of water within its leaves, which then accumulate and encircle the tree in a ground layer of fire-repelling moisture (Griggs, 2015). Knowledge of these adaptations was only gained accidently in 2012, after wildfire swept through a mixed grove of trees that had been planted in the 1980's to test species resistance to various arboreal pathogens. Expecting to find the grove destroyed, they realized, "all the common oaks, holm oaks, pines, and junipers had completely burnt. But only 1.27% of the Mediterranean cypresses had ignited" (Ibid., 2). Amazed by the singularity of this behavior, the researchers concluded that the trees maintain moisture levels within their needles, regardless of high temperatures and dry air. While this adaptation is useful, fire resistant bark and leaves are not unique (Ibid.). As aforementioned, many species of trees are fire-resistant, but their fallen needles and leaves may still accumulate and pose a risk. Unlike other species, Mediterranean Cypress needles create a moisture rich sponge of vegetative matter that surrounds the base of the trees, creating a fireproof skirt that behaves much in the same way as defensible space or exterior sprinkler systems that buffer a structure against encroaching flames (Ibid.). Ongoing research is aimed at examining whether the trees have fire-resistant chemical properties, but the applications of nature's designs for this species are already being explored as a recent study has proposed that Mediterranean Cypress trees could serve as living firebreaks within suitable climates (Ibid.).

Past this range of material, mechanical, and site-oriented design strategies, community-scaled interventions such as early warning systems, evacuation plans leading to shelter, and routes devoted to first responders should be a central part of human fire preparedness, just as they are in nature (Smith et al., 2018). In behavior often misinterpreted as a sixth sense, many species of bat and insect are known to smell and hear fire from many miles away, allowing for time to escape encroaching flames long before they arrive (Nimmo, 2020). Humans may benefit from similar systems of warning, evacuation, and emergency response. Assuming a network of firesafe structures and prevention measures were in place, emergency personnel could go about their work while the wider public is able to flee the area or access sheltered spaces in the community – just as the cavernous wombat burrows of the Australian outback have been known to hold multiple species of small animals in times of wildfire. Regardless of scale or location, the varied methods of fire avoidance listed above may be employed in a range of landscapes to create the human equivalent the fire-adaptive lessons offered in nature, whether they be sealed openings and fire-resistant apertures, the use of insulating, fire-resistant materials, or as defensible space, and emergency preparedness (Smith et al. 2018).

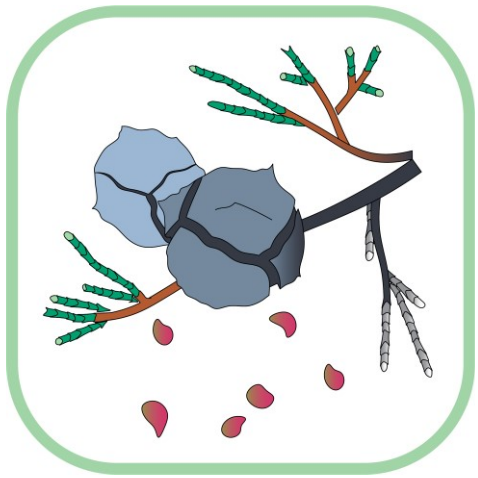

Figure 1: Sergeant cypress dispersing seeds from cones following fire exposure.

The last of the lessons learned from biomimicry strategies used by plants and animals in fire-reliant ecosystems is that many species can adopt a degree of fire-dependence, whereby they are indebted to fire for the performance of certain functions. Most obvious of these is the adaptation of trees like sergeant cypress (Cupressus sargentii), which have evolved to grow cones that only open when exposed to high heat. This serves multiple functions, including improved conditions for saplings more likely to succeed in soils enriched with ash, more likely to be consumed and dispersed by surviving birds and insects in desperate need of food, and a newly thinned understory that allows more light for young trees. Such benefits are complex and varied, but the lessons are evident as many municipalities have policies and standards for prescribed burns to be applied on an annual basis (Ibid.). As with many parts of the U.S., vegetative fuel loads in the west are a risk that remains in place if fire is avoided. So, while the human reliance on fire may be dismissed, the fact remains that people must rely on fire if they inhabit fire-reliant ecosystems.

Fire Adaption Strategies of Indigenous Groups

In the 1987 report entitled, Our Common Future, Norwegian Prime Minister Gro Harlem Brundtland said the following regarding indigenous land practices:

> *These Communities are the repositories of vast accumulations of traditional knowledge and experience that links humanity with its ancient origins. Their disappearance is a loss for the larger society, which could learn a great deal from their traditional skills in sustainably managing very complex ecological systems. It is a terrible irony that as formal development reaches more deeply into rainforests, deserts, and other isolated environments, it tends to destroy the only cultures that have proved able to thrive in these environments (Our Common Future, 1987, 119).*

As plants and animals adapted to fire, so too have indigenous communities inherited the experience of generational knowledge of fire ecology. As Frank K. Lake and Amy Cardinal Christianson explain in their text, “Indigenous Fire Stewardship,” current conditions of drought and high fuel loads may be the result of global shifts in climate and fire-management practices. The fossil evidence and living knowledge of ecosystem management that indigenous communities display in the U.S. and abroad indicates that much can adopted to better serve people living in fire-prone regions (Lake & Christianson, 2019). Indeed, if one is learning to live with fire, indigenous cultures provide a template to understanding how humans may use methods of stewardship rather than prevention. For instance, while prescribed burns are used in many regions, the complexity of “climatic cycles, ignitions sources, fire behavior, and landscape factors, such as how the topography and vegetation/fuels contributed to the natural fire regime and associated landscape fire effects” is something that could take a lifetime to understand within a regional context (Ibid., 2). Yet such strategies existed for millennia as indigenous groups used fire to influence the movement and concentration of certain animals, to encourage the growth of preferred plants or in clearing lands for agriculture (Smith et al., 2018). Many of the fire-prone ecosystems that modern Americans currently inhabit were subject to regular fire regimes practiced by native inhabitants for generations, and the lack of concerted management is likely adding to the flames of wildfires.

Figure 2: Symbiosis between people, plants, and animals in fire-reliant landscapes.

The myth of North America existing as a perpetual wilderness before the arrival of Europeans is one which has led to a lack of maintenance, resulting in landscapes that don't function as they first did when indigenous cultures were displaced (Lake & Christianson, 2019). These cultures functioned as stewards, creating "cultural fire regimes by influencing and diversifying the frequency, seasonality, extent, locality, intensity, and resultant severities of fires." (Ibid., 2) Adding to this shift, the past century featured the enactment of policies of total fire suppression, whereby most wildfires were extinguished whenever possible, often at tremendous cost in the form of money, resources, and human lives as humans often undertake such actions as “smoke jumping” – when aircraft are deployed so that firefighters can parachute into remote locations and fight fires that are inaccessible by roads or waterways. Procedures like this offer a stark contrast to those of indigenous populations, which often increased their application of prescribed fire as their populations grew, used fire to aid food production, and as a safety precaution that would reduce the risk of fire encroaching upon their settlements (Ibid.). While this may seem like a process unrelated to contemporary community design, prescribed fire is an increasingly common means of protection against catastrophic fires, used in sequence with several landscape-based precautions. Of these methods, the popularity of simple non-flammable barriers such as walls between wildland and human settlements has been rising, alongside the said buffer areas that may take form as parks, gardens, water features, and even golf courses. Though a far cry from the landscapes of pastureland and orchards created by indigenous communities, the principle of remains the same (Smith et al., 2018).

CHAPTER 3

PRECEDENTS

Resilient Landscapes

As the number of Americans inhabiting the outer edges of urban spaces, known as the wildland-urban interface, continued to grow at an increase of thirty percent between 1990 and 2010, the likelihood of homes burning in the west also proportionally increased (Kolden and Henson, 2019). In addition , the landscape in much of the American West was greatly altered when colonists halted the ancient indigenous practice of cyclical controlled burning (Rethinking Our Resilience, 2019). Yet people in some parts of the west are learning from the past. While many communities have grown without consideration of wildfire incidence, the town of Montecito, California witnessed catastrophic fires in the early 1990s and began a program of landscape mitigation beginning in 1994. Implementing policies such as community education, vegetation removal, tree thinning, fire-resistant species selection, infrastructure planning oriented toward fire response of roads and city personnel, and ordinances aiming to increase defensible space and home retrofits, the city essentially hardened the landscape to wildfire (Kolden and Henson, 2019). Twenty-three years passed before this process was tested as the 2017 Thomas Fire burned 281,893 acres, moving rapidly toward Montecito, where officials projected four to five hundred homes would burn. Plans were followed and the landscape performed in such a way that only seven structures were burned (Mitigating Wildfire, 2019). Such results demand analysis, offering a range of policies and landscape alterations that could greatly improve the outcome of a wildfire within the wildland-urban interface.

In the words of University of Colorado Denver professor Brian Buma, "Often, after a fire, a community rebuilds, allows everything to grow back and continues to function the same way… We can no longer force the systems to stay the same and we have to adapt with them.” (Sturtz, 2019, 1) In addition to adapting to existing fire patterns, consideration must be made for changing weather and wildlife patterns, which are being altered by changing climates. As some areas experience drier, windier weather, increased fuel loads due to a lack of cyclical fire and possible ecosystem disruption by factors such as invasive insects, the chances of catastrophic wildfire are further exacerbated (Kolden and Henson, 2019). To counter these odds, communities may learn from Montecito and other municipalities that have proactively sought to improve landscape in the face of wildfire.

With the establishment of a town fire specialist position, Montecito began a broad program aimed at reducing fire likelihood through: fuel reduction conducted in partnership with utility companies seeking to clear dry vegetation near electric infrastructure; thinning and removal of understory brush and establishment of shaded fuel breaks meant to slow fire velocity; neighborhood programs to remove and chip wood and debris from private properties; surveying and improving defensible space strategies; limiting fuels along public and private roads, widening fire lanes, and improving emergency vehicle access; and conducting a Community Wildfire Protection Plan (CWPP) that indicated areas vulnerable to ember attack, and where fuels should be further removed (Mitigating Wildfire, 2019). In addition to these remediations in landscape composition, the municipality sought to gather spatial data related to evacuation plans, water access, and possible staging areas for firefighting equipment and personnel (Ibid.). Together these elements created an infrastructure of fire-readiness long before a fire event occurred.

While the powers of municipalities to prepare the landscape for fire are many, the participation of the public proved an essential element in Montecito and elsewhere. With the enactment of stricter building codes banning combustible elements such as cedar shake, sealing of eaves and entry points to flying embers, and even mandating wider driveways for equipment access, the community was asked to participate in their own safety measures (Ibid.). The success of these strategies was finally tested when evacuations for the Thomas Fire were ordered and residents were able to flee while firefighters were unimpeded from establishing containment and fire-retardant lines in prescribed locations, successfully safeguarding hundreds of structures from encroaching flames. All these policies merged to successfully stem the progress of the Thomas Fire, saving the residents of Montecito from enormous losses.

Fire-Resistant Structures

When considering the design implements of fire-resistant structures, current conventions tend to stress the need for fire-resistant materials coating rooftops and facades, but fire researcher Justin Leonard believes most of these approaches are only "skin deep," as façade and roof materials may reduce ignition potentials, but they don't make a building "inherently robust" (Aliento, 2020, 3). Asserting that code must look at the whole building, Leonard asserts that wear and tear can compromise a structure's skin, exposing insufficiencies within a roof, wall, or subfloor system, where little to no fire-retardant material may have been incorporated (Ibid.). So, for those who seek to build or retrofit in ecosystems that are bound to burn, the logical next step is to assess success stories in which firesafe structures have withstood the flames, as “The key to survival is to understand the unique way in which a wildfire will attack your home.” (Milne, 2020, 1)

One such success story of a structure that resisted a catastrophic fire can be seen at the home of engineer named Chris Arai, who spent fifteen years building and fire hardening his home in Healdsburg, California. Central to his efforts were the incorporation of elements such as a steel roof, façade composed of concrete and plaster, the fireproof sealing of eaves and overhangs, a thirty-foot perimeter of defensible space, fire-retardant gel applied to windows and doors, sprinkler systems encircling his property that were able to drench all fuels before the flames arrived, along with an independent power source for pumps, and connection to a ten thousand gallon pool (Abadi, 2020). While this is but a sample of the possible approaches to fire-retardant structural design, Arai’s efforts were so successful that his home and outbuildings were the buildings unburned when the Kincaid Fire consumed his neighborhood in 2019 (Ibid.). While this structural performance has been the exception to the rule in recent years, the approaches undertaken by Arai and others could be employed on a massive scale to better prepare properties for wildfire within the wildland-urban interface.

When assessing the structural risks of wildfire, one must begin by addressing the three primary sources of ignition, which include: wild born embers and the points at which they spark a structure; heat radiating from adjacent fuels; and via direct contact with open flame (Gibson, 2018). Of these concerns, embers are by far the most problematic as, “70% to 90% of the houses lost to wildfires,” are ignited by these tiny flares able to drift over a mile in heavy winds, causing fires to jump and spread far faster as they land in crevices and crannies in buildings and the surrounding landscape (Ibid., 62). Second to embers, the greatest threat to structures during wildfire is radiant heat that may ignite siding or rooftops, and poses great risk to doorways and windows, which can break and allow fire to ignite interior elements (Ibid.). Fortunately, there are many design options and material applications that can greatly reduce the likelihood of burning.

While early building codes were meant to prevent interior fires from spreading, wildfire codes must account for exterior materials, as well as unknown conditions such as humidity, wind speed, temperature, and the length of time it may take a wildfire to pass (Milne, 2020). Assuming "you can design your home to withstand this massive but brief exterior attack, it has a good chance of survival" (Ibid., 1). As seen with the home of Chris Arai and others, California building codes now address a series of steps that a property owner may take to prevent wildfire loss. The first of these is site layout, wherein the ideal distance between a structure and surrounding vegetation is one hundred feet, with various options for filling that space with low-growing fire-retardant plants, patios, driveways, water features, and fire-resistant decking (Gibson, 2018). Additional consideration should be given to slopes, with the ideal topography being flat and easily traversed on foot and in automobiles, with consideration for firetruck parking and turnaround points (Milne, 2020).

Beyond site, fire-resistant roofing, siding, and apertures are an essential to repelling embers and radiant heat (Gibson, 2018). Such materials can be quite attractive and in keeping with local aesthetics, using roofs made of metal, terra cotta, or concrete, and siding such as stucco, face brick, tile, adobe, rammed earth, concrete block, or metal siding (Milne, 2020). Once such materials have been selected, special attention must be paid to their application and sealing of all joints, overhangs, soffits, vents, and underfloor areas, with California fire code prescribing quarter inch metal wire mesh screens on all air vents (Ibid.). Additionally, “if you have a particularly severe exposure, your architect can design a firewall, a more technical solution sometimes used in large urban buildings” (Ibid., 2). Once these elements of the façade have been addressed, one may consider windows, the weakest point repelling fire as even radiant heat may shatter glass and ignite interiors. Therefore, options such as double glazing with tempered, fire safety, or wire glass may be used, as well as the addition of, “roll-down metal fire doors built into the roof overhangs or side recesses, and released automatically by fusible links” (Ibid., 2). These fireproof shutters effectively seal window to flame, with mechanisms that are triggered when exposed to smoke or high heat. In sequence with such window systems, metal core exterior doors and metal panel garage doors can effectively retard heat without warping (Ibid.).

Beyond these structural measures of wildfire prevention, the system that may have had the greatest influence over the survival of Chris Arai’s home was the integration of a sprinkler system designed to saturate the structure and landscape (Abadi, 2020). Given the likelihood of losing power during a major fire, Arai and others are wise to incorporate off-grid electrical generation and storage methods to power pump systems. In Arai’s case, this power source was found in photovoltaic panels, which also act as a flame-retardant rooftop barrier to embers (Milne, 2020). In sequence with this system, a large water source such as a pool, cistern, or pond would allow a substantial quantity of water to be rapidly dispersed (Ibid.).

Combined, these measures may be employed to dramatically reduce structural risk, while also increasing overall structural performance and longevity. While some of these measures are incorporated in building code for certain states or local municipalities, the potential for implementing them in existing structures is clear and should be considered by the owners of any structure located within the wildland-urban interface, especially those in proximity to fire reliant ecosystems. To do otherwise is to ignore the inevitable.

Fire-Adapted Community Design

While the interventions of property owners can greatly affect the survival of individual structures and the people and possessions sheltered within, the breadth of scale that these events assume are such that in 2017, "Fires scorched 10 million acres in the western U.S. and federal fire-suppression expenditure surpassed a record $2.9 billion" (Rethinking Our Resilience, 2019, 1). As wildfire events increase in size, temperature, and frequency, the likelihood of whole communities being engulfed increases to the point that individual preferences may overruled as municipalities consider of stricter controls on where people are able to build and rebuild. After all, many places face greater degrees of uncertainty as "climate change will continue to produce longer, drier fire seasons with substantial burning that will consume residential developments" (Ibid., 1). As with sea level rise and desertification, the ramifications of these changes may result in human migration and the wholesale redesign of entire communities as people are forced to adapt or relocate to more hospitable locations. In the case of the wildland-urban interface, such movements may be as simple as a return to centralized towns with commercial cores integrated with apartments, condos, and townhouses, surrounded by compact clusters of single and multifamily homes.

While a comprehensive community redesign has yet to be implemented in response to the recent catastrophic wildfires in the American West, there is precedent of theoretical application of such ideas as evidenced in the work of a Rice University architecture student named Vivian Schwab, who has proposed plans for the redevelopment of Santa Rosa, California. After the fire-dependent foothills at the north end of the city were engulfed in the 2017 Tubbs Fire – killing twenty-two people and destroying over six thousand homes – Schwab "developed a 25-year plan that would form two new communities within Santa Rosa," with plans calling for varied levels of density and design approaches that mitigate the risks of wildfire (Williams, 2020, 1). In a radical step, Schwab has proposed the removal of structures in the city outskirts, and replacement with homes and businesses built in closer proximity to the urban core, which also offers greater access to mass transit and cultural amenities. While such steps may seem drastic, similar measures are already being implemented in many municipalities in the U.S. and abroad following natural disasters such as the floods and hurricanes that are also increasing in scale and frequency as the global climate continues to shift (Hallegatte et al., 2011). Like steps made to distance people from volatile coastlines and wetlands, buffers of uninhabited space are an integral part of Schwab's proposal, as she suggests that irrigated parks, farms, and vineyards could serve as zones of defensible space that, "create an effective gap between fuel sources," reducing risk as expanses of homes and infrastructure are consolidated (Williams, 2020, 2).

Indeed, even as people in Santa Rosa and other communities continue to rebuild to higher standards of fire resistance, the risk of destruction remains as “neighborhoods are now being rebuilt in place. It is a short-term solution towards the return to a status quo, but that status quo isn’t sustainable, and stakeholders need to think strategically about how their decisions now will play out in ten or twenty years, under even more uncertain conditions” (Ibid., 1). With thousands of homes within the Santa Rosa area located within the fire prone wildland-urban interface, a comprehensive redesign such as the one suggested by Schwab may prove the best path toward firesafe community planning.

CHAPTER 4

SITE CONTEXT

Regional Setting

Between the expansive urban corridors of Los Angeles and San Francisco, the town of San Luis Obispo, CA offers a central point seen as a convenient stopover or base for exploring the surrounding beach towns, artist communities, and outdoor activities. Within this area is a variety of ecosystems ranging from chaparral scrub to coastal redwood forests, affording the chance to view wildlife that varies from antelope, bears, and birds to whales and elephant seals. While doing so, people can enjoy outdoor activities such as hiking, biking, surfing, and kayaking (San Luis Obispo Travel, 2019).

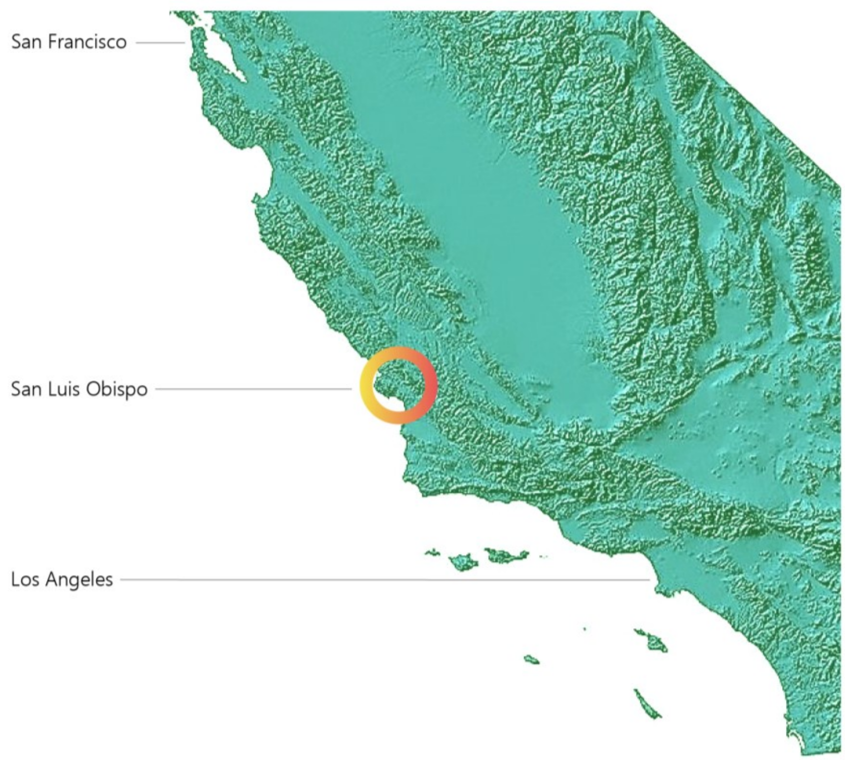

Figure 3: Contextual location of San Luis Obispo, California.

Surrounding the valley wherein San Luis Obispo is situated are a series of low mountains and ridges capped with oak and pine trees that follow arroyos and creek beds like veins of green descending to the valley floor. Outside of these lush crevices of vegetation, scrub and grassland is common. Within all of this diversity, a shared trait of most species is the adaption and dependence upon wildfire as a source of cleansing and rejuvenation (City of San Luis Obispo, 2010). This fire-oriented symbiosis was understood and came to be encouraged by those who originally settled this fertile valley bordered by the Pacific Ocean and Coast Ranges.

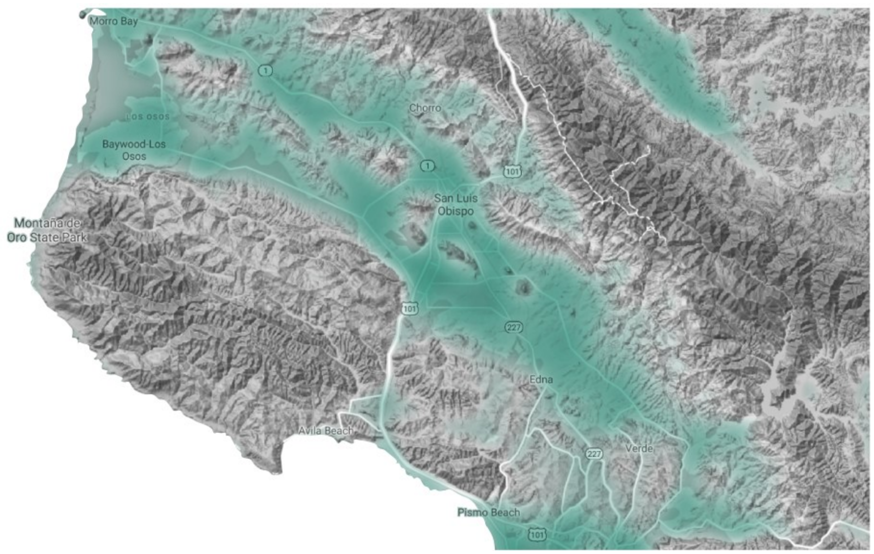

Figure 4: Topographical map of San Luis Obispo and immediate surroundings.

When Native Americans established permanent settlements in the area around 10,000 B.C., this dependence was understood as the Chumash and Salinan tribes maintained “one of the most densely populated areas of pre-historic California,” which flourished until Spanish settlers arrived in early mid 1600’s (Ibid., 6). As one of twenty-one California communities established by Franciscan missionaries in the late 1700’s, Mission San Luis Obispo de Tolosa became the center of Spanish activity in the town, with a plaza and gridded streets built to serve as a center of commerce and civic life. The native populace was gradually subjugated as control of the region transitioned to Spain, then Mexico, and finally to the United States of America in 1850 (Visit Mission San Luis Obispo, 2020).

Waves of migrants then came to work on farms and ranches in the area, redefining the city as it expanded. With the establishment of California Polytechnic State University in 1901, San Luis Obispo gained greater cultural relevance and added jobs in education, business, tourism, and healthcare that helped the city to grow to its current population of approximately 50,000 (San Luis Obispo Travel, 2019). Today the city offers cultural amenities such as museums, performing arts, sporting events, farmers markets, wineries, and a range of activities oriented toward California Polytechnic State University's twenty thousand students (Student Life, 2021). The result is a place with multiple influences evidenced in the urban design and building methods, materials, and styles wherein adobe, Victorian, Spanish revival, modern, and contemporary architecture reflect the city's past and present.

Site in Focus

Within San Luis Obispo, a site was chosen with the wildland-urban interface in mind, as the city features an intermingling of farm, forest, field, suburb, and urban enclaves. In a suburban neighborhood bordering San Luis Obispo High school and the grassy hillside of the town's east edge, a site was chosen for analysis and a reimaging of community, landscape, and form (figure 5).

Figure 5: Single-family residential site located at a suburban edge.

Beginning with an assessment of roadways, buildings, and paths, a research-based assessment of community and site conditions was made (figures 6-12). Beyond the built environment, natural elements such as vegetative fuels, water sources, prevailing winds, likely fire paths, and Santa Ana winds were analyzed as relates to their influence on fire incidence and emergency response. The last of these features is of particular importance, as the phenomenon known as a Santa Ana is a reversal of prevailing winds caused by high pressure in the high desserts of neighboring Nevada that causes hot, high-speed winds to flow down the mountain passes of southern California. In the handful of times that this happens each year, the likelihood of wildfire greatly increases (Murphree et al., 2018).

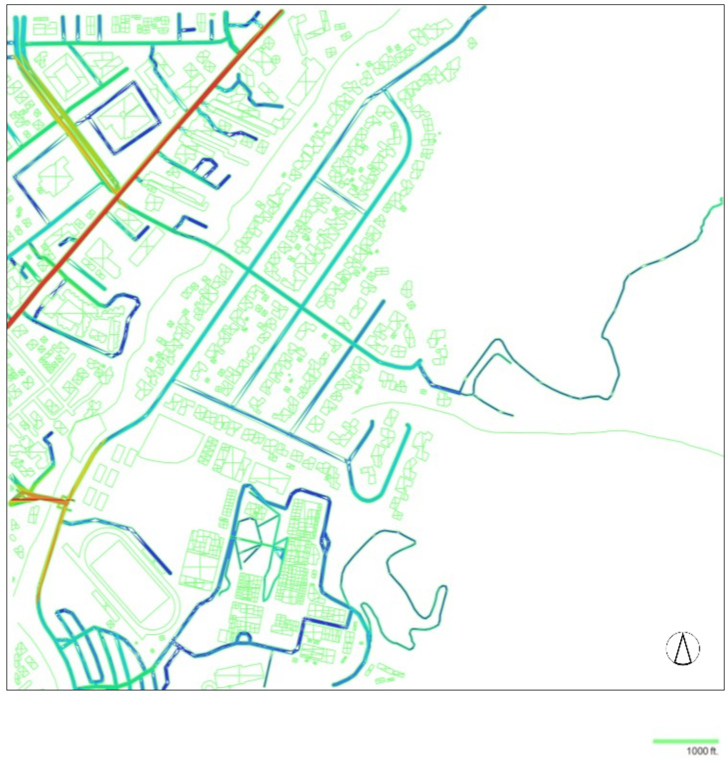

Figure 6: Volumetric connectivity expressing likely traffic loads.

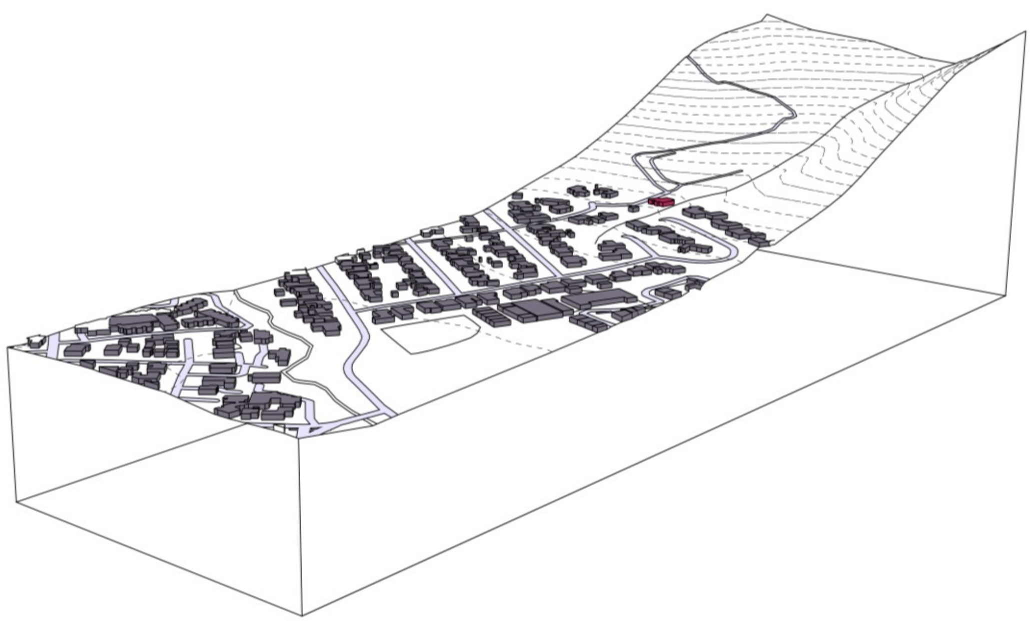

Figure 7: Assessment of roads and buildings adjacent to site (indicated in red).

Figure 8: Assessment of vegetative fuel loads adjacent to site.

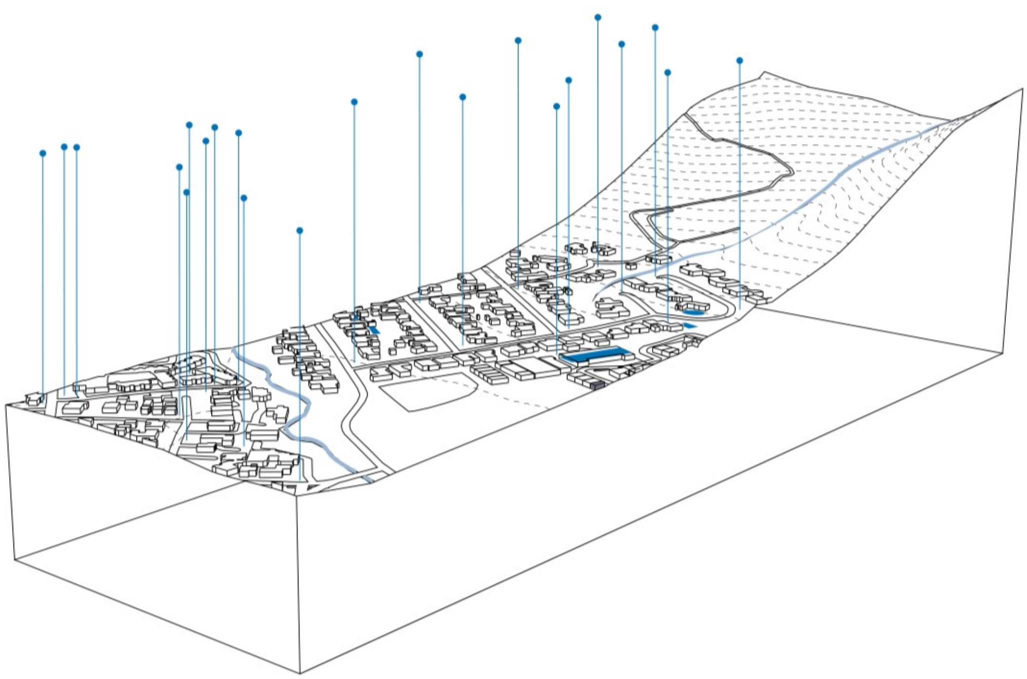

Figure 9: Assessment of water sources (hydrants, pools, creeks) adjacent to site.

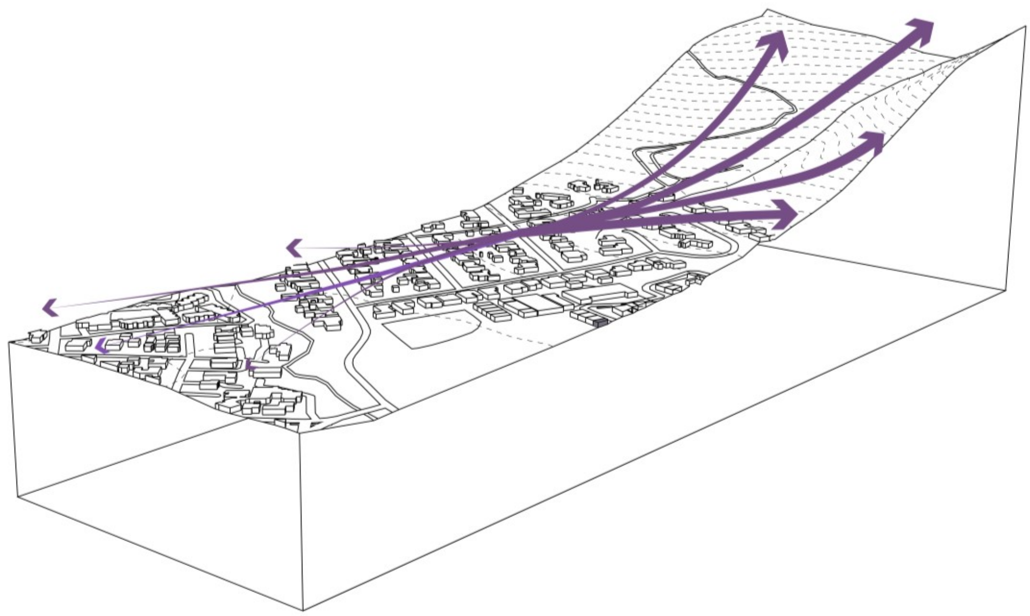

Figure 10: Representation of prevailing winds in the area.

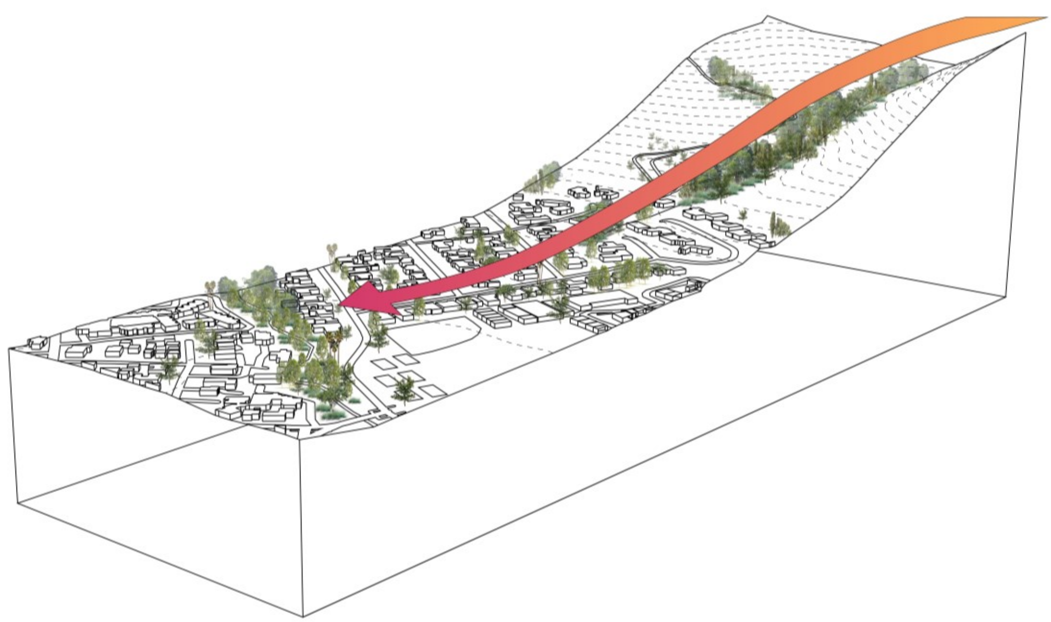

Figure 21: Path of Santa Ana winds descending hillside.

Figure 32: Map displaying behavior of Santa Ana winds in Southern California.

CHAPTER 5

DESIGN APPROACH: COMMUNITY

Overview of Design Approach

Following research into the responses to fire exhibited in nature and indigenous groups that have collectively adapted to life in fire-reliant ecologies, a system of lenses has been established. Within this system, a series of flagship species and human adaptations have been highlighted, giving a better sense of how these responses may be interpreted through contemporary fire-mitigation strategies. The result is a method based in biomimicry and indigenous design that is adapted to contemporary building practices, delineated by the degree of design interventions applied through successive levels of minimum, medium, and maximum mediation strategies.

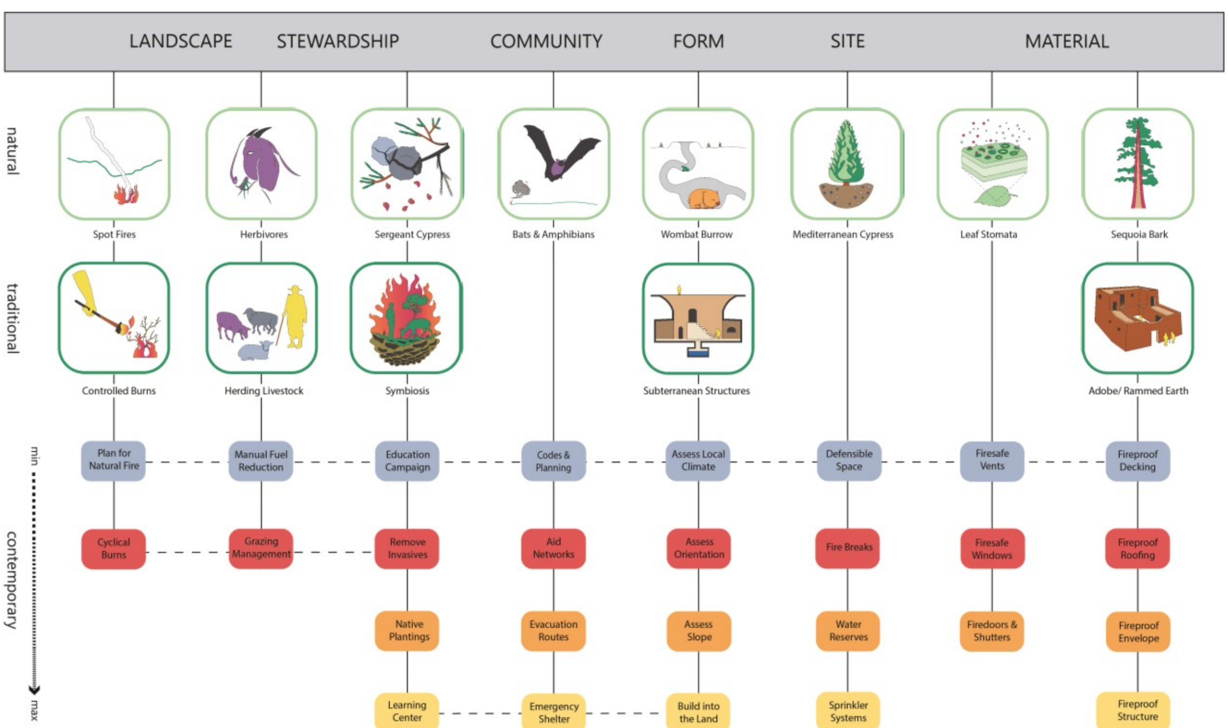

Table 4: Biological, traditional, and contemporary fire interventions.

Mediating Now and the Inevitable

At the core of community-based fire preparedness within fire-dependent places such as San Luis Obispo is the establishment of codes, zoning, and planning policy oriented toward widescale fire preparations. The basis of such preparations can be found in the behavior of many animals, including bat colonies wherein the inhabitants of a space are adequately sheltered, and function collectively as their mutual survival is dependent on group action. The result is a community with early warning systems in place via smell and sensitivity to atmospheric pressure, with clear routes of evacuation, expedient means of transit, and often with a secondary shelter planned before the arrival of wildfire. Beyond these simple steps, humans have many additional concerns related to safety, preservation of property, and a greater degree of difficulty with evacuation. To account for these liabilities, a community design and response plan should be prepared to reduce the likelihood of individual property damage through collective action.

Figure 13: Bats & amphibians live in groups that can detect & evacuate fire zones.

Beyond biological responses to fire, inspiration is found in the management processes of indigenous groups that initiated many of the best practices currently in place within communities facing fire risk. These include assessing risk based on site, weather, and planning for future incidence of fire based on this accumulated knowledge. In modern municipalities, this can be replicated through assessment and planning based on fire vulnerability and risk of wind-born embers entering an environment. Within contemporary society, people benefit from the ability to catalogue and analyze this data with computers equipped with geographic information systems that can better process and display topography, weather patterns, fuel levels, and transportation data used to plan landscape management, water access points, evacuation routes, and firefighter staging areas. From this information can be crafted clear plans of action for varying budgets and timeframes (figure 2), assuring that municipalities are designed for wildfire survival.

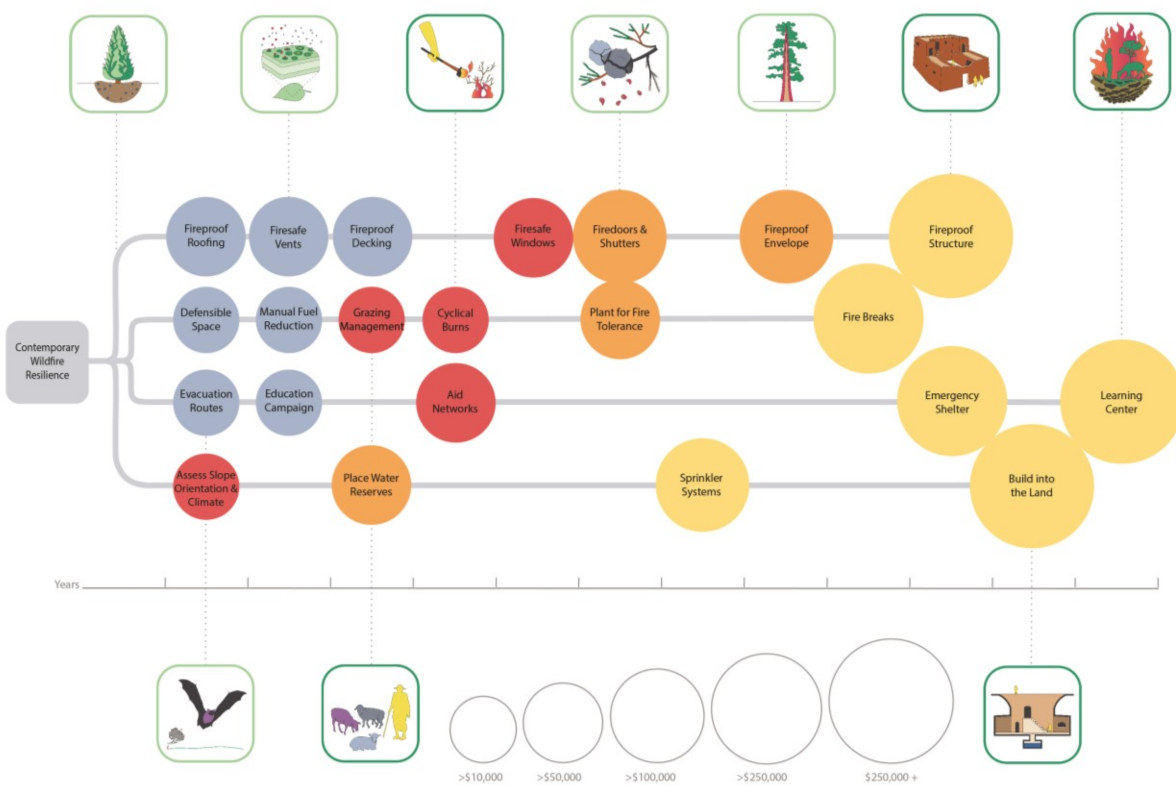

Table 2: Time and cost of contemporary fire interventions

At the basic level of minimum mediation planning for wildfire, the process begins with education for community members to increase understanding of the natural process of wildfire within regional ecosystems, combined with policies guiding the behavior of communities and individual property owners. Specifically, education programs could begin with public school programs teaching fire ecology to grade schoolers, combined disbursement of digital and paper media to homes and within community spaces and gatherings. Once an education campaign and public policies aiming to increase defensible space and home safety retrofits (further discussed in subsequent chapters) have been initiated, a municipality may continue the process of civic preparedness with principles of vegetation management. At the core of minimal mediation strategies meant to cause minimal disruption to the community fabric is the creation of fire breaks in the form of one hundred foot corridors wherein vegetation has been manually removed (see figure 14). While such corridors would require large initial investments, the upkeep of such swathes would be manageable as shown in prevalence of utility corridors maintained throughout the nation. With such a system in place, the process of vegetation removal would be complimented by the organized clearing of dry fuels near infrastructure such as roads, the selective thinning of trees and brush, the establishment of smaller shaded fuel breaks meant to slow fire movement, and the planting of drought and fire tolerant species that are less likely to add fuel to wildfire. In addition, many of these measures were historically employed by indigenous groups as a thinned understory added to community safety and encouraging the presence food plants and animals, while contributing to overall ecosystem health and diversity (Lake & Christianson, 2019).

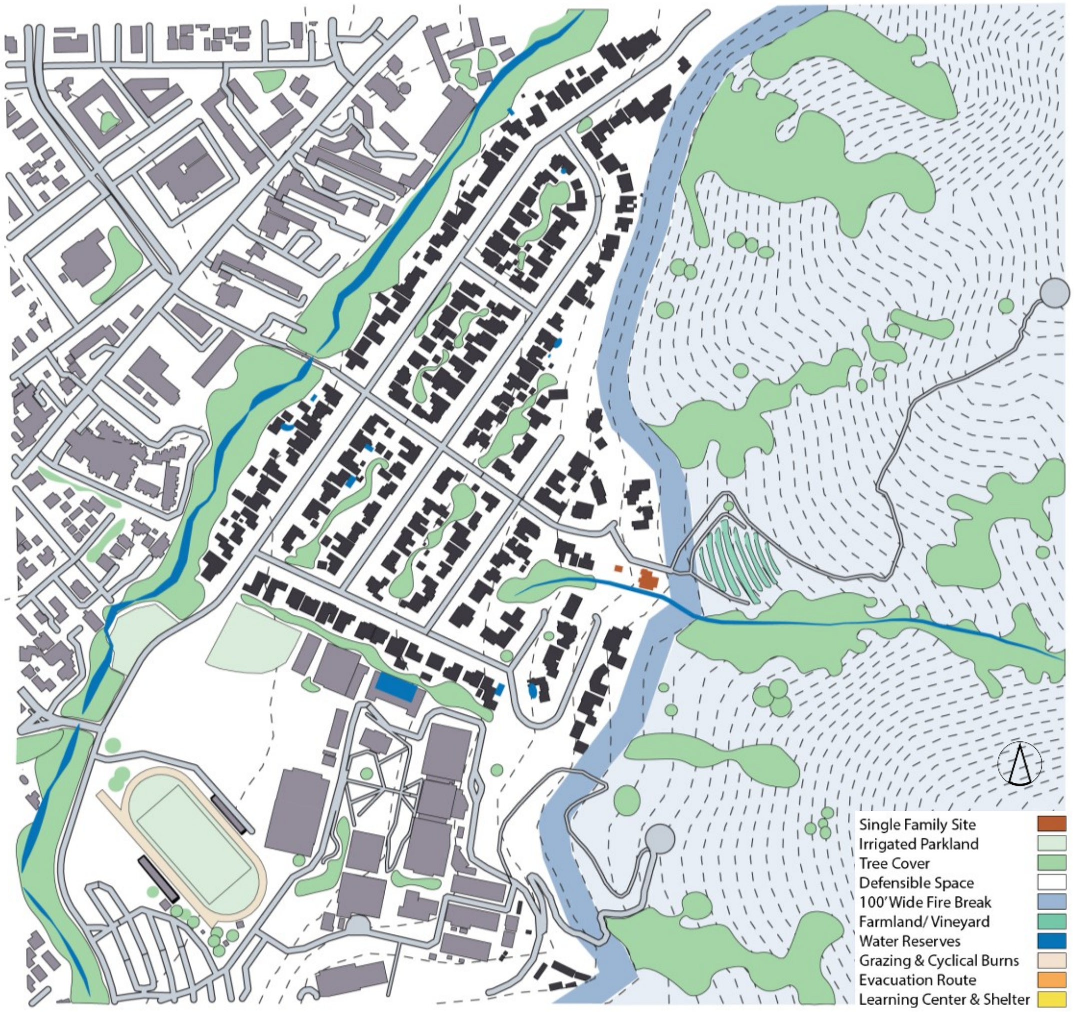

Figure 54: Minimum mediation - protects existing structures.

After the establishment of a minimum responses to wildfire, communities facing recurring wildfires may require an expansion of infrastructure to account for the needs of large-scale emergency management. Therefore, a medium scale of mediation initiatives provides an expanded scope of the mitigation (figure 17) of wildfire risk that includes augmentation infrastructure and, in extreme cases, community design. Such configurations would be best executed within newly planned neighborhoods as the need to appropriate property could otherwise prove costly and unpopular.

First and simplest of such augmentations would be the replacement of any flammable traffic, address, or evacuation signage and their posts, while assuring that such infographics are visible to emergency personnel and evacuating residents. Following these minor steps, roads used for evacuation and emergency response should be assessed in terms of width for fire lanes and truck access, steepness of grade, vertical clearance, turnaround points, staging areas, and overall strength of engineering. Once assessed, these elements may require retrofitting to increase size and strength, while assuring that evacuation routes are made clear and logical to residents.

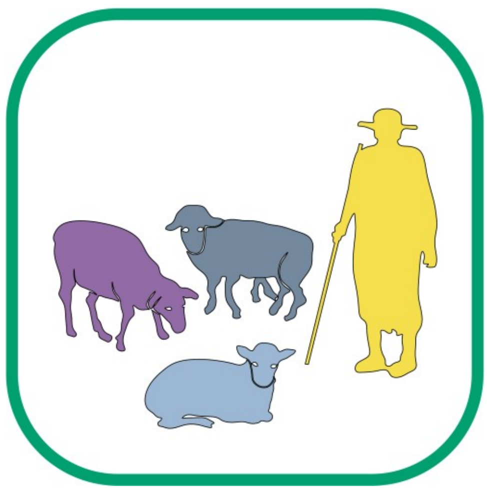

Figure 15: Grazing as fuel management.

Beyond the built aspect of large-scale public works, one of the simplest means of landscape management is one of nature and humanity's oldest methods of alteration. Through the grazing of herd animals, biological adaptation and indigenous practices have long been able to control the severity of wildfire through incremental removal of dry understory vegetation (Westervelt, 2019). Integration of grazing within contemporary fire management practices has been shown to increase the effectiveness of fuel reduction policies, while adding visibility to such initiatives, improving ecosystem functions, offsetting the costs of manual fuel removal, and connecting people to their pastoral ancestry. Indeed, in many cases grazing programs are of mutual benefit to communities and individuals participating in the husbandry of goats, sheep, or cattle.

Figure 16: Prescribed fire cleanses and protects.

While grazing management is an effective passive means of fuel reduction, the weakness of this method lies in the selective consumption of fuels by herd animals that may avoid some plant species in favor of others, leaving large loads of potentially combustible material uneaten. The solution lies in the all-consuming appetite of fire, as shown in the use of prescriptive burns, a practice employed for millennia. While contemporary standards of controlled burning rightfully limit the territory and participants involved – with permitting and certification closely controlled – the benefit is fire's inability to consume material that has already burned.

Inevitably, the controls required for the implementation of grazing management and controlled burns would be robust, and best employed in communities with buffers between inhabited areas and wild landscapes. Such controls can be seen below (figure

17), where firebreaks stand adjacent to irrigated farmland or vineyards, drastically reducing the chances of flames encroaching on inhabited property.

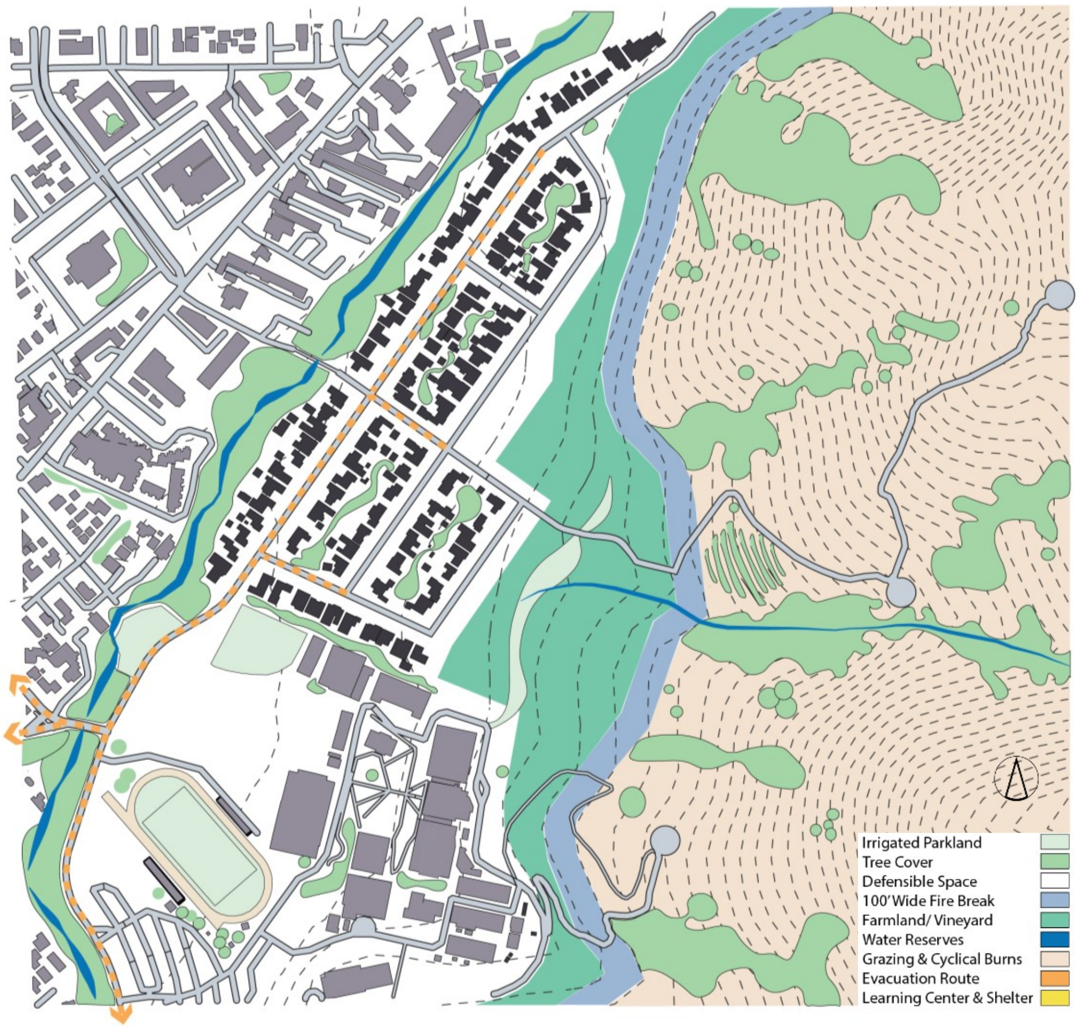

Figure 67: Medium Mediation - ideal for new neighborhood design.

In communities in which flames have encroached and caused structural loss, extremely fire prone areas may better serve the community through the integration of the previously mentioned mediations, along with the addition of larger areas for farm to be used by growers and multiuse parkland to be enjoyed by residents and wildlife. Within this extended area of greenspace, fire preparedness and civic enjoyment could be bolstered through the establishment small reservoirs that might serve as an emergency water supply for firefighting, while adding to the range of animal species, and to the overall enjoyment of community members.

Last and likely the most visible of the maximum mediation initiatives would be the construction of a wildfire ecology learning center where residents and visitors could expand their understanding of how wildfire is an integral part of the landscape in San Luis Obispo and beyond. Along with this function of learning and connection, the facility and its surrounds could be designed for fire resistance and might double as a community fire shelter to be used in times of emergency, especially if evacuation of the area is impeded. The facility's siting near the high school would also reduce traffic loads should fire encroach on the area, enabling students to shelter in place. Measures such as this would ultimately contribute to regional knowledge of the processes and solutions outlined here, while helping to create a safer, well prepared community.

In sequence with this dissemination of information, local planners may need to research and assess the realities of changing weather and wildlife patterns as climate change affects the area. More than likely, the result will be areas facing hotter, drier, windier weather patterns that result in increased fuel loads and the risk of trees and shrubs being killed by invasive insects such as bark beetles, greatly increasing the likelihood of windswept wildfires moving faster and hotter through such areas. Considering the compounding risk associated with such conditions, city planners could better craft plans to counter the risks, while also informing citizens of the local realities that may guide the community toward firesafe policies and individual practice as the individual property owner is made to participate protecting themselves and their neighbors. It is this dialog between municipalities and community members that will determine what program and design mediations are enacted, as the process is ultimately dependent on public will and a clear understanding of the process of community-based fire preparedness within fire-dependent places such as San Luis Obispo.

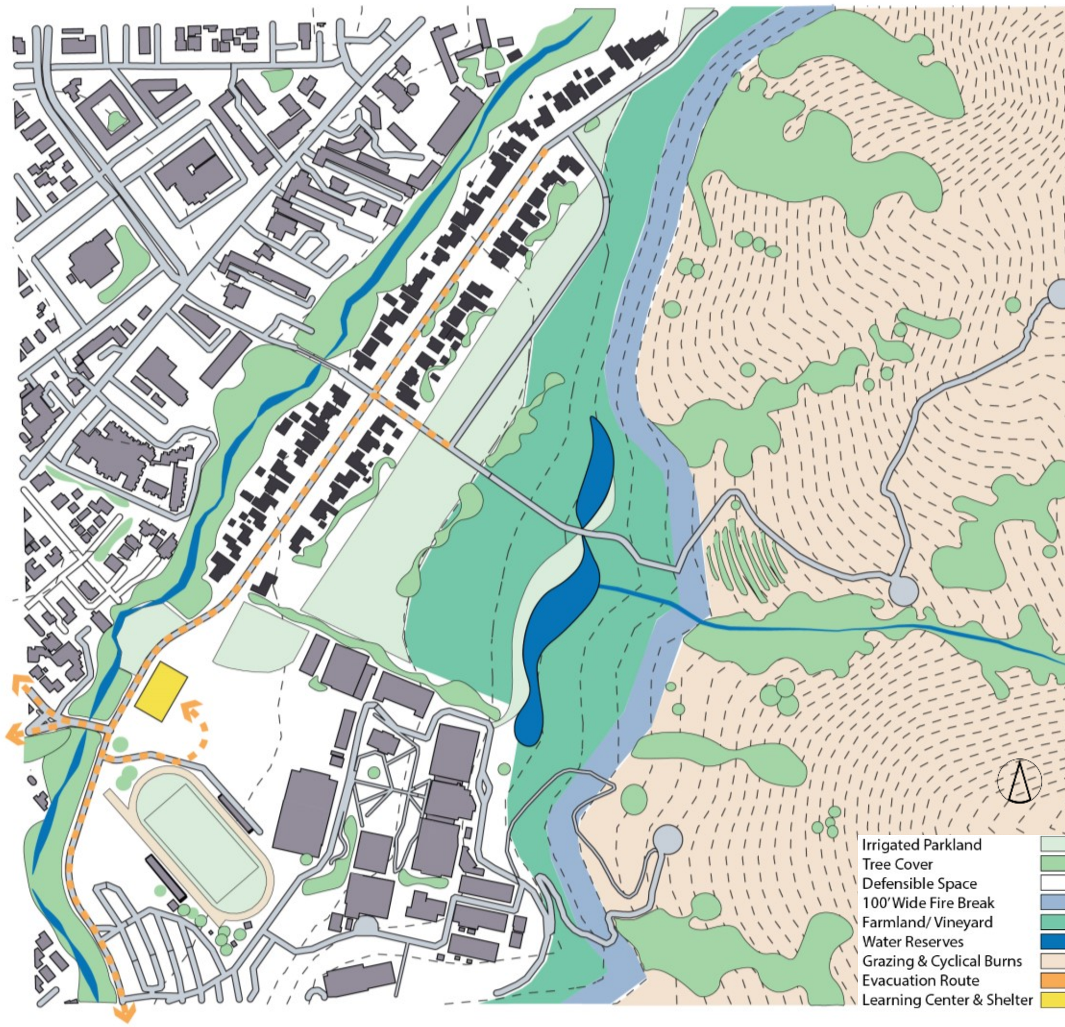

Figure 78: Maximum mediation – for areas lost and extremely fire prone.

CHAPTER 6
DESIGN APPROACH: LANDSCAPE

Fire Cleansing Reliant Ecosystems

While many of the broad-scale elements of landscape interventions aimed at increasing fire-preparedness have been discussed in relation to whole communities, it is ultimately up to independent property owners to secure the safety of their land and structures through a variety of landscape alterations. Beginning with a thorough understanding of site elements such as typical wind, heat, and humidity levels and how these interact with topography and fuel loads, the individual can select appropriate building sites or make appropriate alterations for existing structures. The subtleties of these elements are numerous, as even building orientation can influence fire behavior given sunnier and dryer west and south facing slopes retaining less moisture than those of opposing directions. In addition, low points between peaks – such as the single-family site discussed here – are paths of least resistance for wind and wildfire. Given these complexities, it is essential that property owners protect themselves from wildfire via research, site assessment, and implementation of varying degrees of landscape mediation.

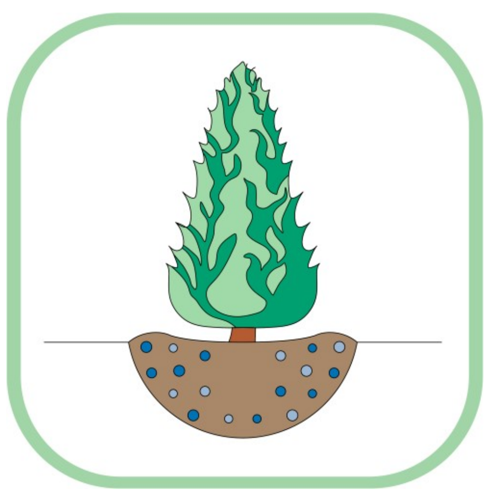

Figure 19: The Mediterranean cypress creates defensible space.

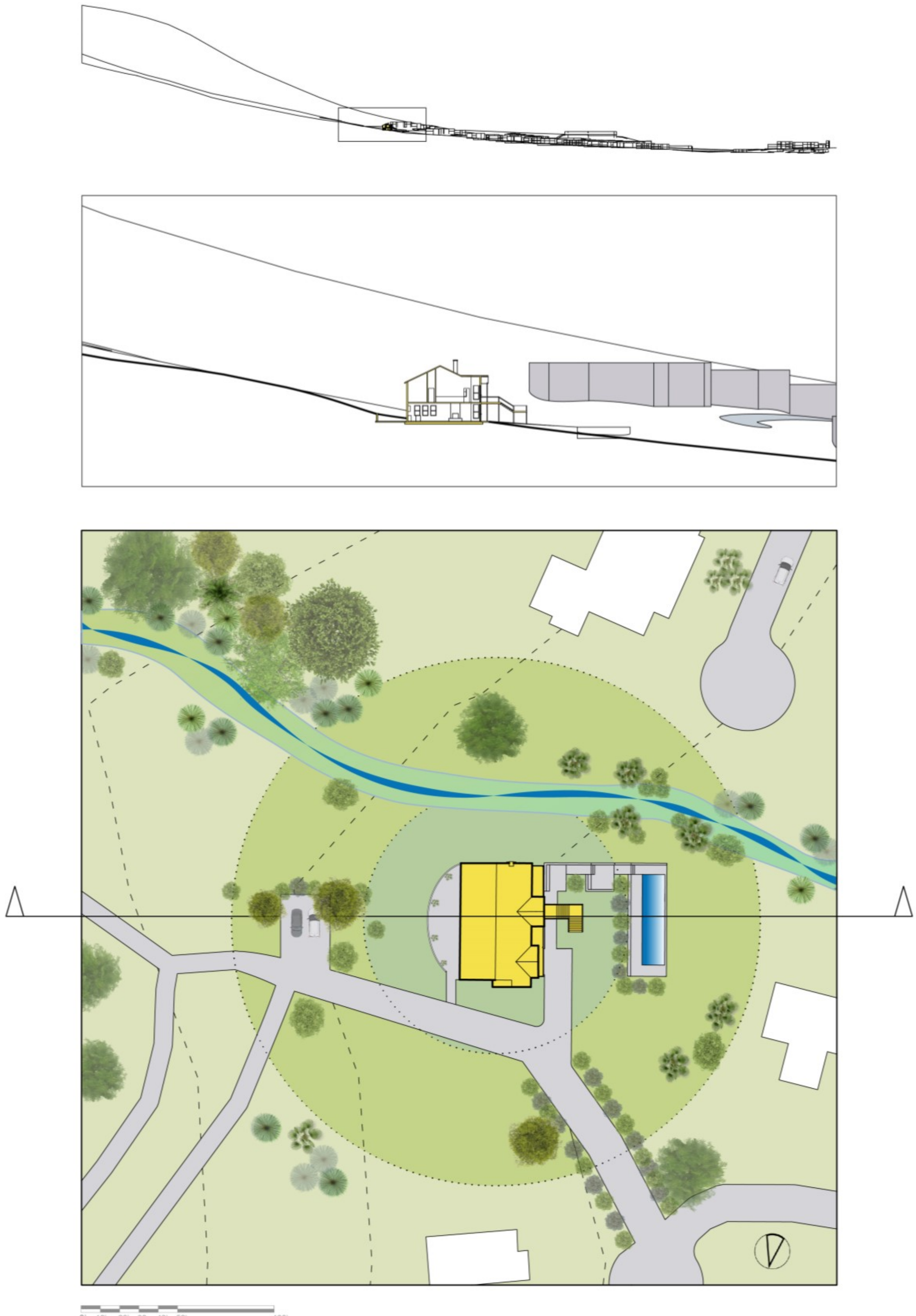

Figure 20: Sectional and plan views of landscape mediation of existing home.

Of great importance to landscape management in wildfire dependent ecosystems is the creation of defensible space in the way of a radius of thirty to one hundred feet in which vegetation and built elements are made firesafe through proper design, maintenance, and material selection. The first step in this process should be the removal of combustibles within the immediate thirty foot vicinity of the structure, as firewood, debris, flammable patio furniture, combustible wooden decking, and fire-prone vegetation that can create catalysts for wildfire. Such materials can be substituted with metal furnishings, irrigated groundcover, rock gardens, hardscape like concrete and stone patios, fire resistant decking materials, and water features such as ponds and pools that may act as fire barriers and emergency water sources if municipal sources are damaged or drained during a fire event. Should these water reserves need to be accessed by firefighters, they should be clearly marked with signage, with road access and turnaround points for equipment planned by property owners well in advance. In addition, built elements such as outbuildings, automobiles, fuel tanks, and fences should be placed thirty feet from main structures, or be built of noncombustible materials when possible.

Often the most intensive aspects of the creation and maintenance of defensible space is vegetation management, which may require removal of dry or overgrown vegetation near utility lines and meter boxes, as well as regular thinning of understory plants and the elimination of certain species such as highly flammable evergreens. For most trees, this means elimination of all branches ten feet or lower, as well as the creation of ten feet of open space between branches to prevent horizontal fire movement. In some cases, species selection can greatly improve the performance of defensible space as plants such as Mediterranean cypress are able to resist burning due to biological features such as fire-resistant compounds within the foliage and sequestering of water reserves in soils that helps to slow or stop fire movement. It is this biological function that drives the process of defensible space in conventional practice, which is ultimately one of the simplest and most cost effective ways to protect a building from wildfire.

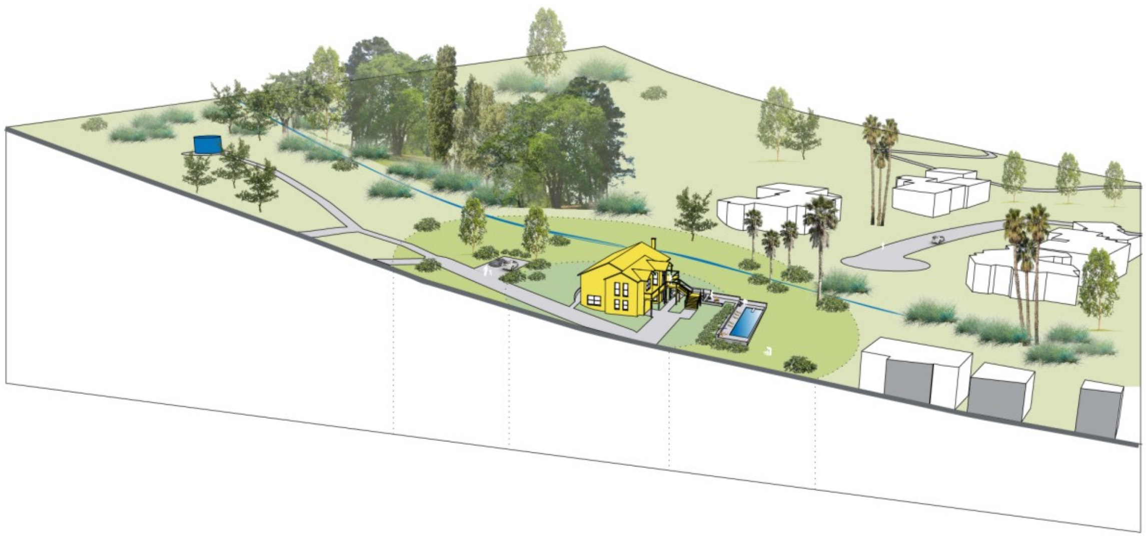

Figure 21: Perspectival view of landscape mediation of existing home.

In the case of sites where fire poses a particularly clear risk, additional landscape elements may be built such as larger water reserves, integrated pumps, off-grid power sources and battery storage, and exterior sprinkler systems designed to saturate structures and their immediate vicinity. Consideration of the placement of these elements is important, as rooftop photovoltaic panels can provides an additional barrier to embers and flames, while batteries will explode and burn when exposed to high temperatures. As indicated in figure 21, the construction of elevated water tanks can provide gravity-pressurized water reserves that may be used to saturate a property as fire approaches without the need for power or pumps. Should this system fail, pumps and off-grid power sources may tap into water reserves such as wells, swimming pools, or cisterns.

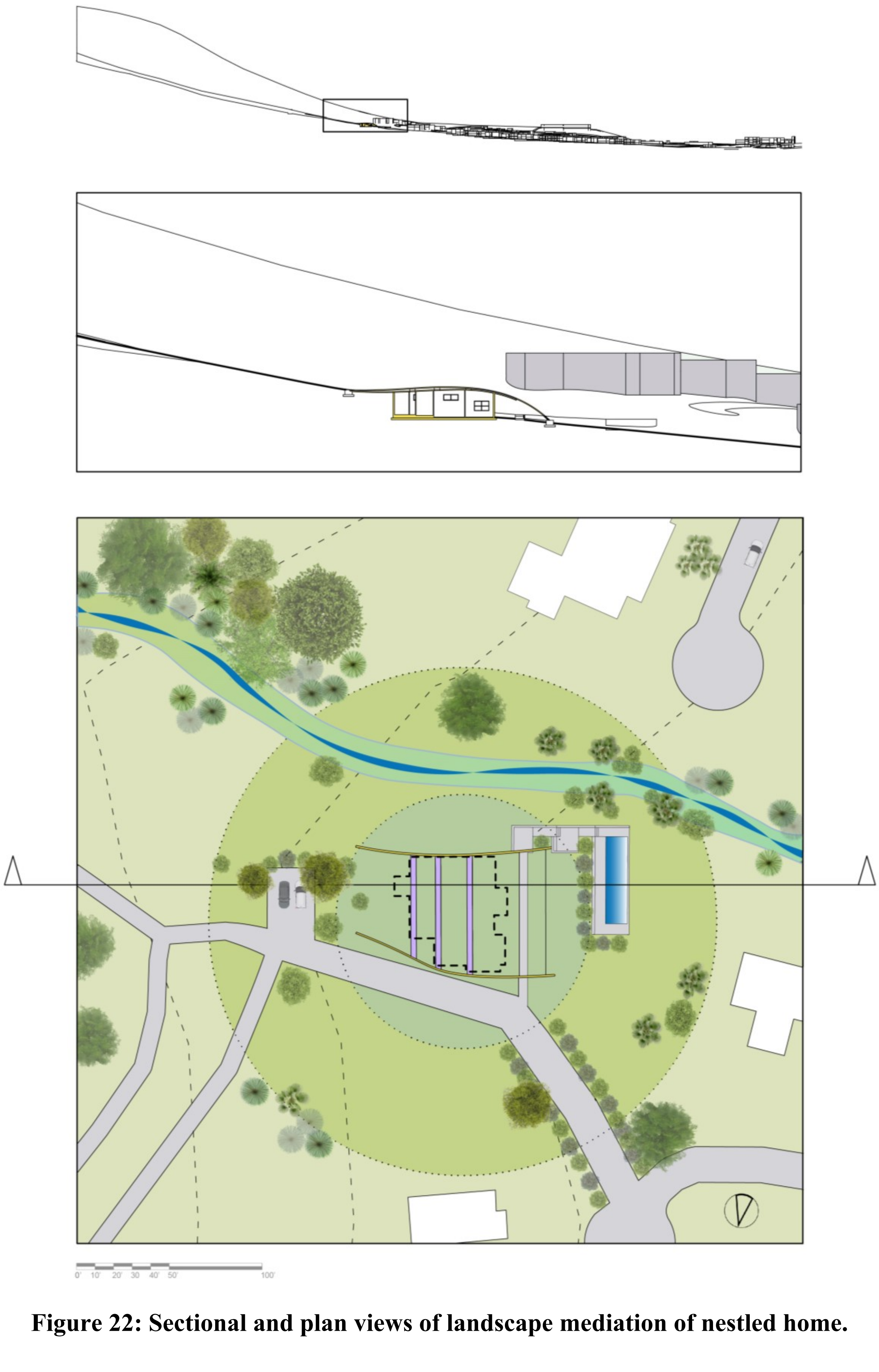

Figure 22: Sectional and plan views of landscape mediation of nestled home.

While the options for defensible space implementation are many, risk remains outside of individual property owner control in sites where slopes are extreme, and when neighboring properties pose hazards. The latter of these concerns can be best approached by neighbors working collaboratively to create mutually defensible space between adjoining structures and property lines. For the individual, wildfire should always be framed as an element that has no perception of property lines or personal preference.

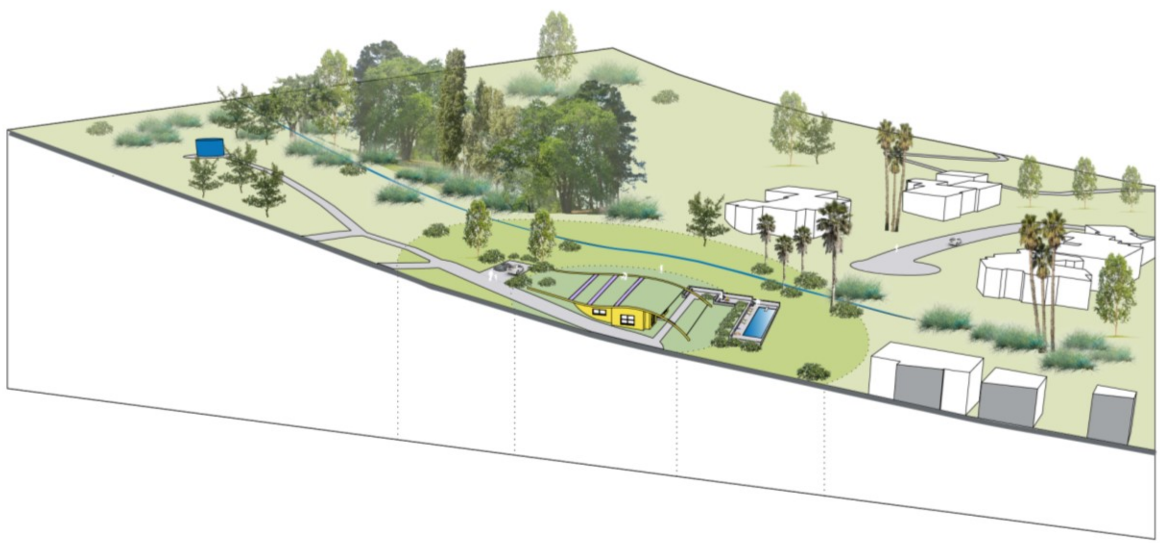

Figure 23: Perspectival view of landscape mediation of nestled home.

With the fickleness of fire in mind, the scope of risk is broadened when considering landscape management when firebrands, flying embers, and heated gases can make dangerous situations more unpredictable. While these hazards will be further discussed in the subsequent chapter, it is noteworthy that landscape elements such as decking, fencing, and outbuildings can harbor sparks and embers within gaps and edges, smoldering until the point that they ignite. These types of factors must be mitigated through orientation meant to avoid fire path exposure, the design of forms sealed from all angles, and correct choice of material in the landscape.

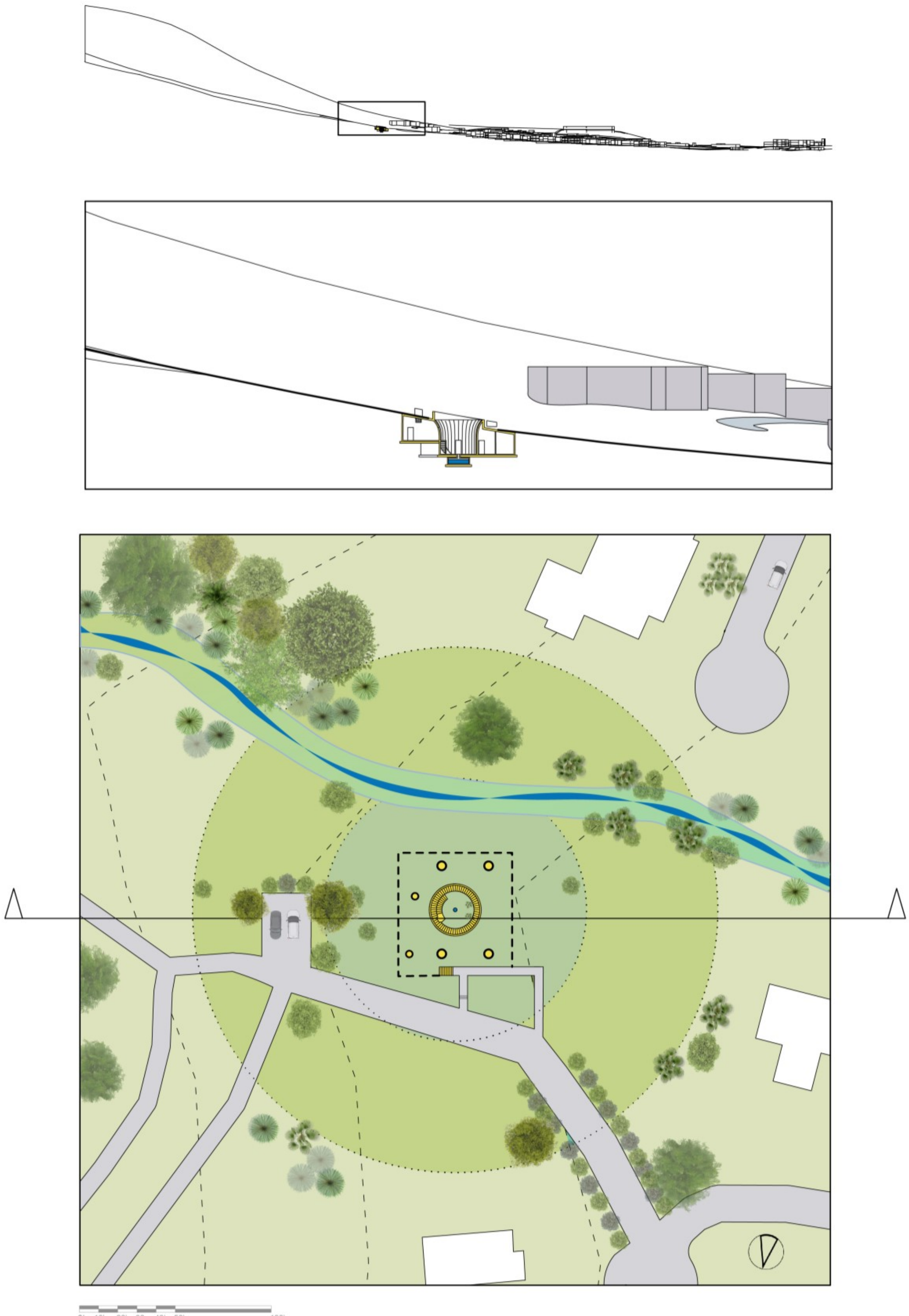

Figure 24: Sectional and plan views of landscape mediation of burrowed home.

Much like the proposed provisions for mitigating wildfire risk on the community scale, the landscape of private property may require fortifications such as firebreaks or firewalls designed to shield combustible components. Additional built elements include previously mentioned sprinkler systems that can saturate landscapes and structures. With structurally mounted sprinklers, these are often placed on the ridges and eaves of roofs, where they are activated by sensors functioning much like bats and amphibians triggered in response to smoke and heat. While technically outside of the purview of landscape, exterior sprinkler systems can function in sequence with interior sprinklers, improving structural survivability should fire penetrate exterior defenses. Additionally, a worst case scenario may justify the use of chemical products manually applied to an exterior, effectively mimicking the biological behavior of firesafe species like Mediterranean cypress. Provisionally, the outlined landscape mediations will greatly increase the overall fire-tolerance of an individual property, yet the survivability of structures in largely dependent on the site, form, and material elements incorporated throughout.

Figure 25: Perspectival view of landscape mediation of burrowed home.

CHAPTER 7
DESIGN APPROACH: STRUCTURE

Building like a Sequioa

When researching aspects of structural wildfire resilience, conventional wisdom often focuses on fire-proof materials – yet deeper analysis indicates that design should extend to site, aperture, form, and mechanical elements. To that end, it is important to frame the discussion in terms of what mediations may be applied to existing structures versus new construction. Clearly, the range of options and total costs can vary tremendously for both existing and new construction, so exploration of wildfire mediation strategies begin with the most essential measures, as outlined in table 2.

Beginning with the existing structure located on the designated site in San Luis Obispo, a range of design and material applications may be applied to increase the likelihood of structural survival. Perhaps the most vulnerable component of a structure is the roof, as it offers a broad surface area on which embers and flaming debris may ignite and penetrate the building envelope. While the odds of ignition are increased by valleys and intersections, the roof material is of paramount importance. For this reason, it is essential that homes with flammable roofs located in fire-dependent ecosystems be replaced with noncombustible assemblies. Options for such roofs include metal shingles and panels, fiberglass reinforced asphalt shingles, fire-treated wooden shingles laid over a fireproof underlay, or clay and concrete tiles that offer the additional benefit of slowing heat transfer via thermal mass. The last of these options is especially relevant in the case of property owners who may be less vigilant when it comes to removing combustible debris from roof valleys or rain gutters, as burning material may still ignite components below the roof covering. It is also important for roofs sheathed in materials other than clay or concrete to be monitored for signs of age as they become more susceptible to fire over time.

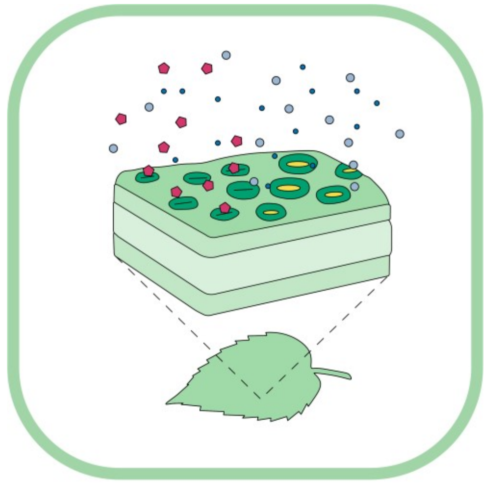

Figure 26: Leaf stomata of plant adapted to seal itself from heat and noxious gas.

Second to roofing material, components in the periphery of roof assemblies such as soffits, joints, overhangs, and vents are the elements of a structure that are most susceptible to fire hazards such as embers and ambient heat. In California, building code dictates that such recesses and ventilation components be made of fire-resistant materials and that vents be screened with quarter-inch wire mesh meant to impede ember intrusion (Milne, 2020). If embers were to enter such spaces as attics, cathedral ceilings, crawlspaces, or ductwork, they could easily ignite a building's interior. While researching the biological adaptations, the design of leaf stomata served as inspiration, as species such as Hawaiian Ōhiʻa lehua trees have adapted so that these 'pores' on leaf surfaces will close when exposed to fire and heated gas. In keeping with this principle, it is important for vents and windows to seal a building's interior from the hazards of wildfire. In response to this adaptation, it is also advised that property owners install automated metal shutters over vents to further protect interiors against heat and flame.

Below rooftops and ventilation systems, the building element that is most likely to fail is a building's window systems, which are vulnerable to flames consuming their casings, as well as radiant heat severe enough to shatter glass. For most buildings within the wildland-urban interface, it is recommended that windows be replaced or installed with an insulated double glazing of tempered, firesafe windows with a low emissivity coating meant to reflect radiant heat. In addition, flaming debris make be carried by high velocity winds capable of breaking many window assemblies. In high wind areas or on sites with dramatic slopes, it may be necessary to mitigate this additional risk to windows with wire glass, or laminated glass that offers a greater degree of puncture resistance. Also, in apertures such as skylights, fiberglass reinforced glazing may be used to further fortify windows that may face heat and flaming projectiles. While the range of fire-resistant glass types are many, they remain only as effective as the casings in which they are held. It is therefore imperative that window frames be made of fire-resistant materials such as aluminum, steel, or treated wood – preferably with insulated internal thermal breaks. Finally, research has shown that window performance is increased with the simple addition of metal screens, which act as another barrier against burning ember intrusion (Fire Resistant Windows, 2015).

Albeit more solid than glass, exterior doors function similarly to windows when faced with flames and heat in that standard assemblies are often made of flammable materials that fail quickly and should be replaced with insulated steel doors designed to withstand fire. Inevitably, the thin, combustible nature of doors and their frames makes them a liability that is often overlooked. This holds especially true for garage door assemblies that are usually made of plywood or thin sheets of aluminum. Thus, it is recommended that garage doors be sealed around their edges, and that they also be replaced with insulated steel models that can effectively retard heat without warping.

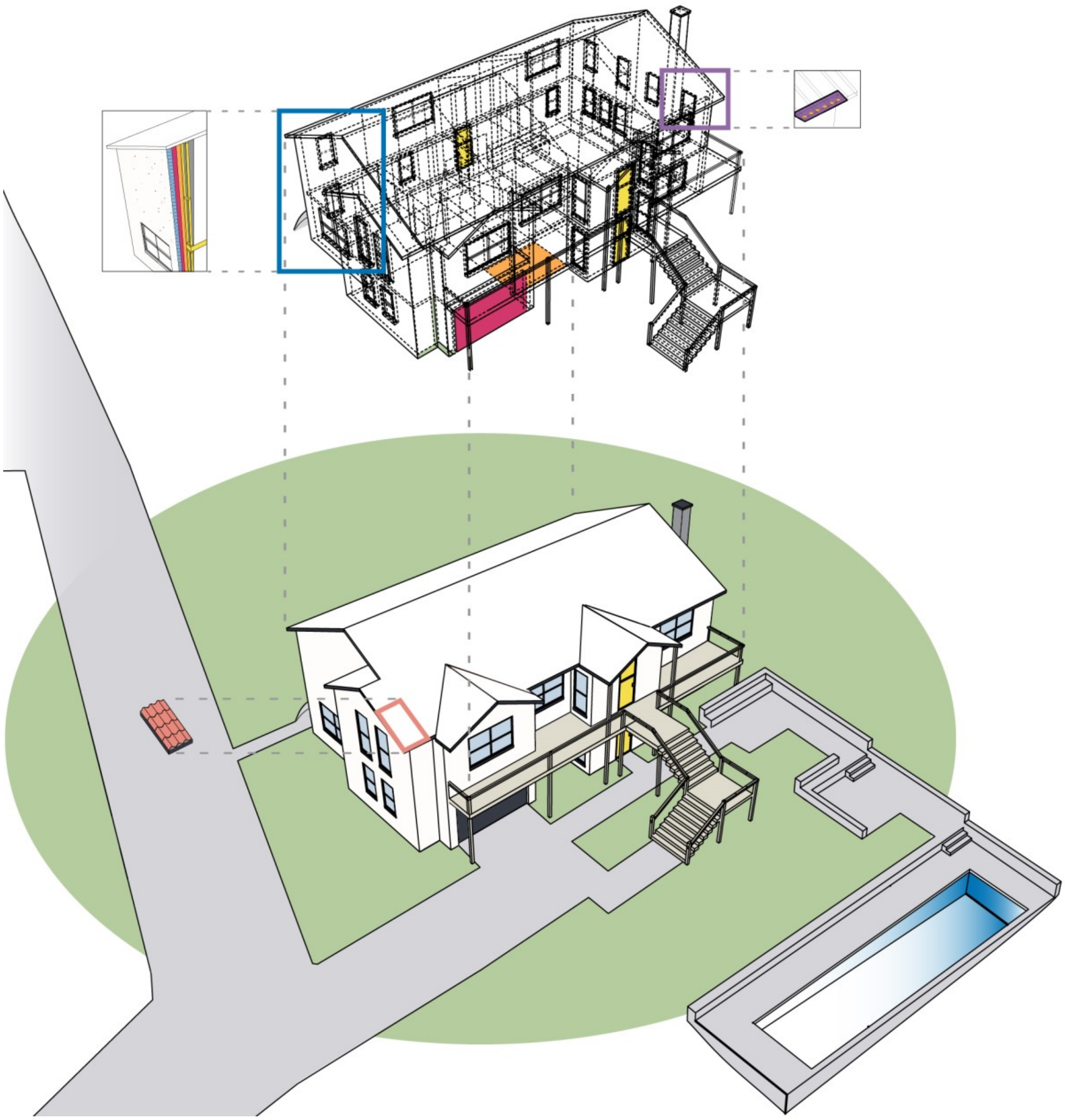

Figure 27: Axonometric view of existing home displaying form and structure.

Figure 28: Sectional view of existing home indicating ground and topography.

Perhaps the most intensive of retrofits possible for buildings facing the risk of wildfire is the renovation of exterior walls that are especially vulnerable to heat and flames when sheathed in combustible forms of siding and may contain flammable materials within their assembly. Fires within walls will likely travel inward and upward, potentially engulfing large portions of a structure. Considering this hazard, the adaptations of giant sequoias (figure 29) – which evolved to grow a fireproof layer of insulation in the form of fire-retardant bark that typically grows six to twenty-four inches thick – serve as an example of how best to protect a building envelope (Howard, 2021). While a building is not able to grow bark, the next best adaptation for an existing structure is an exterior envelope consisting of stucco, fiber cement, metal panels, or wood siding pretreated with fire-retardant. In the case of newly constructed exterior walls, wildfire preparedness is further improved with fireproof structural materials such as rammed earth, straw bale construction, adobe, cinderblock, concrete, masonry, or steel studs. Given such a range of material and construction methods, virtually any contemporary form can be designed with fireproof walls. In the case of rammed earth (figure 30) and adobe (figure 31), the precedence for such construction methods has been established throughout the history of civilization, with examples of such walls standing for hundreds of years (Peris Mora, 2007). Concerns remain in certain climates with high rain and humidity levels that can degrade earth-cased materials, but in San Luis Obispo and much of the western United States this is easily mitigated with maintenance and benign chemicals applied at the time of construction (Abadi, 2020).

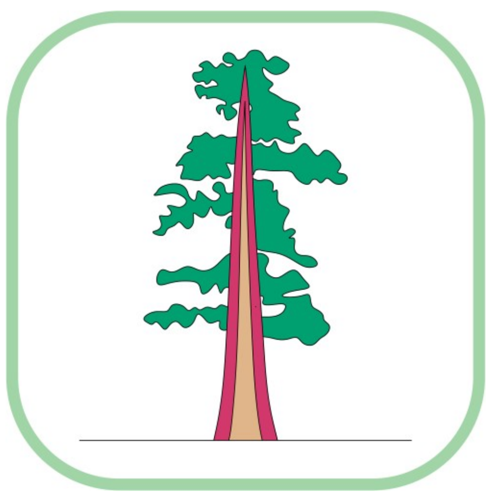

Figure 29: Sequioa bark is a biological response to fire.

While many of the considerations regarding the renovation of existing structures remain applicable to new construction, the ability to weigh concerns related to wildfire preparedness during the design and construction phases allows for greater levels of intervention. First and foremost, the siting of a building can greatly influence survivability as slope, orientation, and climate forces are assessed and mitigated. As mentioned, slope can dramatically influence fire behavior as it speeds up or downhill an accelerated pace when funneled between high points, as shown in figure 28. Ideally, topography such as this is avoided, but when given such a site structural orientation can play a role in minimizing risk when narrower walls face the likeliest path of wildfire. Given a narrower wall facing danger, the likelihood of direct exposure to heat and flames is reduced in proportion to surface are, with embers, firebrands, and debris less likely to accumulate at the base of exterior walls before and during a fire event. While considering surface area, it is also advisable that windows and doorways be minimized on facades facing the highest risk of fire exposure.

Another benefit of new construction in fire-reliant ecosystems is an individual's power to shape structural form and details. While the possibilities are many, options such as the ability to design a building with impervious or absent overhangs can minimize concerns related to eaves and soffits at the roof edge, and material choices in all parts of the envelope can be made fireproof for an extended length of time. Another way to extend structural resistance to fire exposure is with the integrated design of exterior metal rollers tailored to encase and seal window and door assemblies when heat fire approaches. Much like sensor-triggered sprinklers, rolling shutters can close without the need for manual operation, creating a window barrier that is impervious to wildfire. While these systems can be added to existing structures, they often pose an aesthetic conflict for all but the most utilitarian of property owners as their bulky housing is much easier to conceal within newly constructed walls. Ultimately, the freedom to incorporate such elements provides a significant advantage when building from the ground up.

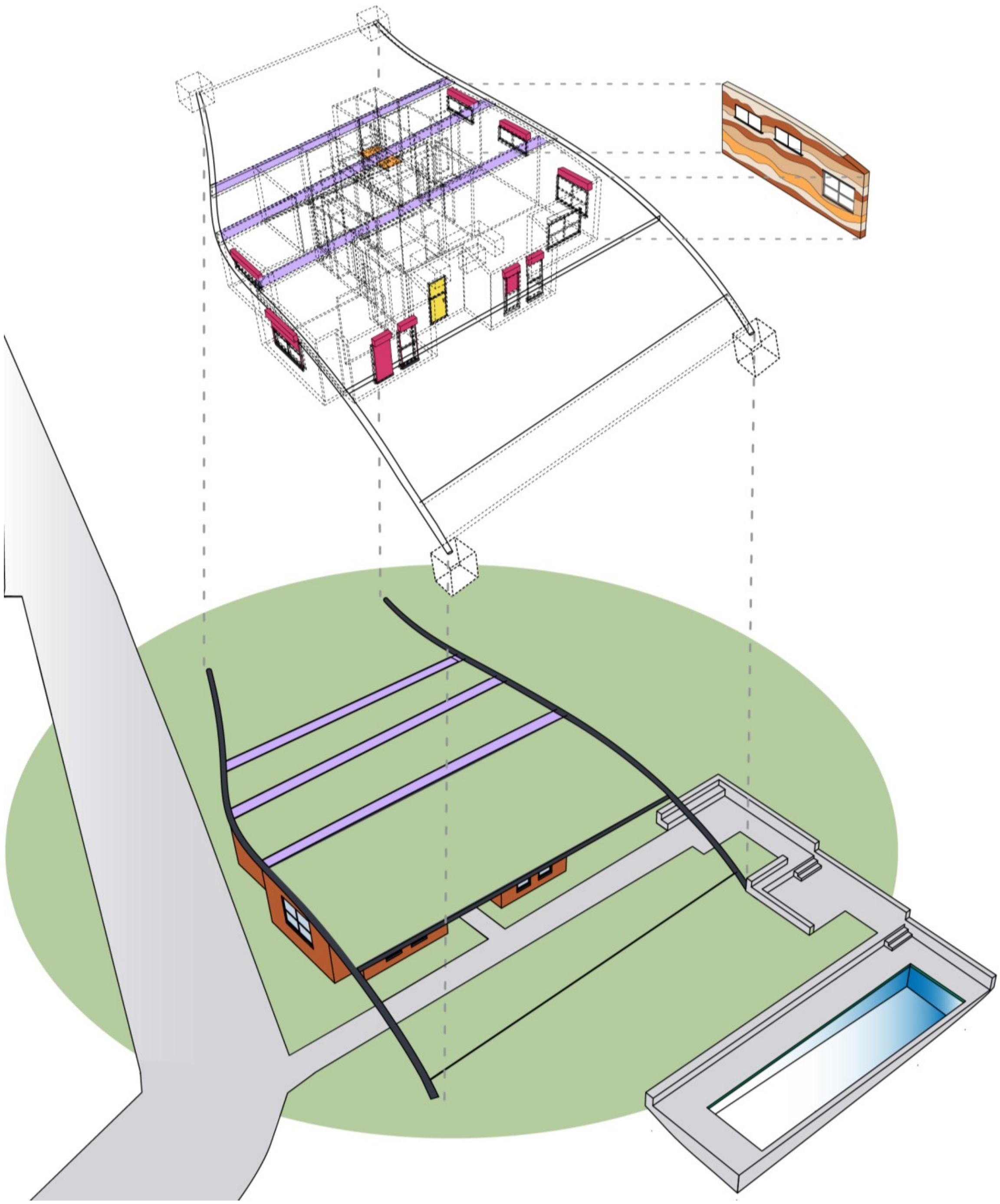

Figure 30: Axonometric view of nestled home displaying form and structure.

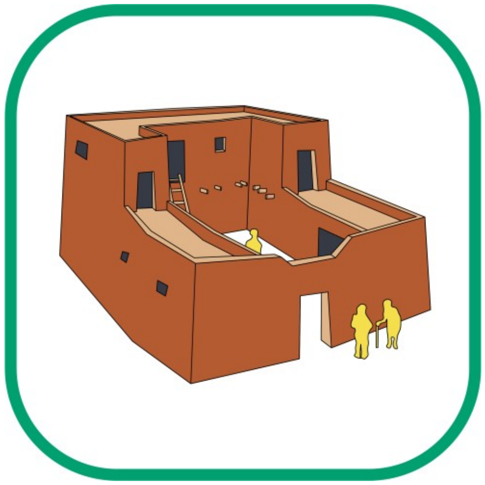

Figure 31: Adobe is a sustainable, highly insulative construction technique.

When looking at construction from the ground up, even the foundation is component that should be considered when planning for wildfire, as the likelihood of direct contact with flames is high in this lower section of a structure. Often, conventional building practices incorporate breaches in the form of vents and crawlspaces that can be penetrated by heat, flame, and embers. This basis of construction must be designed to repel such risks, and the best way to do so is with non-flammable materials such as cinderblocks or poured concrete. Should this option be precluded, wood or steel beams may be made firesafe with the application of fireproof insulation and sheathing. Alternatively, this method could also be used to remediate existing structures, thereby assuring that a building is impervious to fire from top to bottom.

Looking beyond conventional building form, various design elements have been viewed through the lenses of biomimicry and indigenous design, along with the consideration of conventional construction methods. With initial ideas ranging from buildings elevated above the flames, to tunneled forms burrowed beneath the flames that may roll over ground level, the finalized proposals are posited as forms that incrementally recede into the landscape.

Offering a hybrid approach between conventional form and a fully burrowed structure, the first proposal for new construction takes cues from fictional Hobbit holes and retro earth ships, while shirking fanciful aesthetics. The form nestles itself into the hillside, taking shelter from the hazards of wildfire driven up or downhill by prevailing weather patterns and anomalous Santa Ana winds. In addition, this relationship with the ground minimizes exposure to fire while improving insulative performance derived from layers of earth adjoining half the exterior walls, along with a green roof that swoops over the top (Mitchell, 2020). The result is a form that offers a conventional interior while retaining the merits of a whimsical and functional building able to withstand wildfire.

Figure 32: Sectional view of nestled home indicating ground and topography.

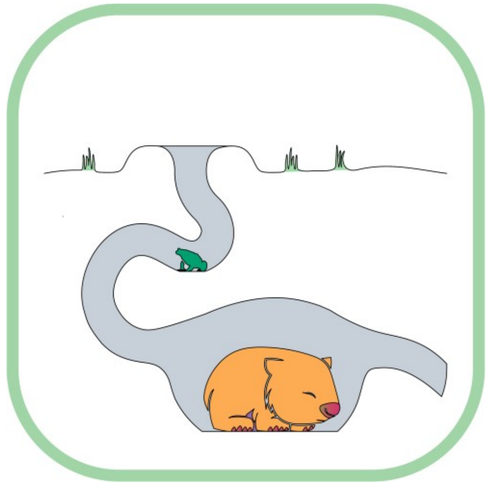

Figure 33: Wombat burrows are natural subterranean fire shelters.

Taking a broad step away from conventional building form, the need to reconsider the situation of structures built within the wildland-urban interface led to questions of how a building might sustain regular wildfire exposure without taking damage due to the strain of heat and resident displacement. The result is a form largely inspired by the adaptations of wombats and other burrowing animals (figure 33), as well as the subterranean villages of North Africa, Southern Italy, and Northern China – where communities have moved underground to cope with aggressive neighbors, harsh environments, and limited building materials (Erdem and Solak, 2005). While underground living may seem unappealing to modern sensibilities, the need to reevaluate how people occupy fire-dependent ecosystems is reinforced every fire season. In addition, many design elements such as courtyards, lightwells, and skylights can be incorporated to give a sense of natural light and connection to the land and sky.

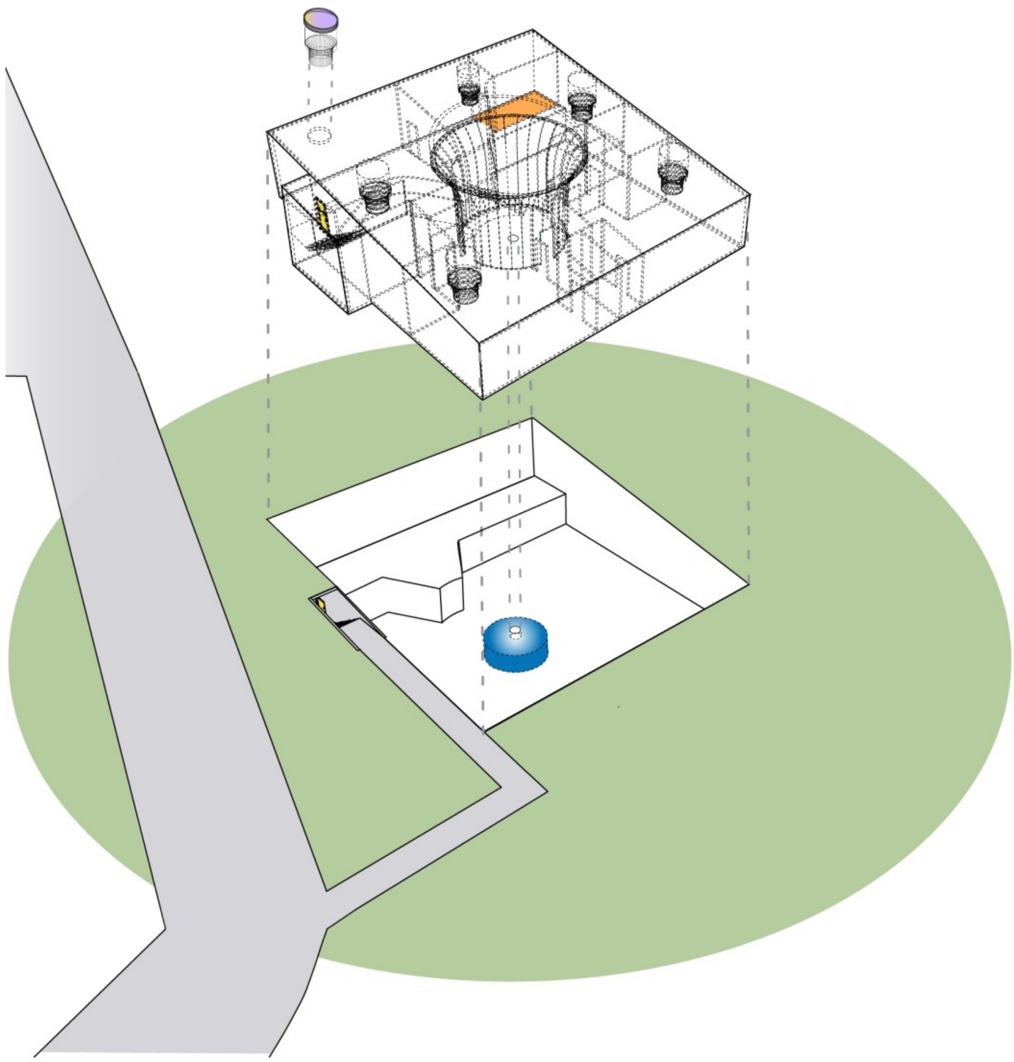

Figure 34: Axonometric view of burrowed home displaying form and structure.

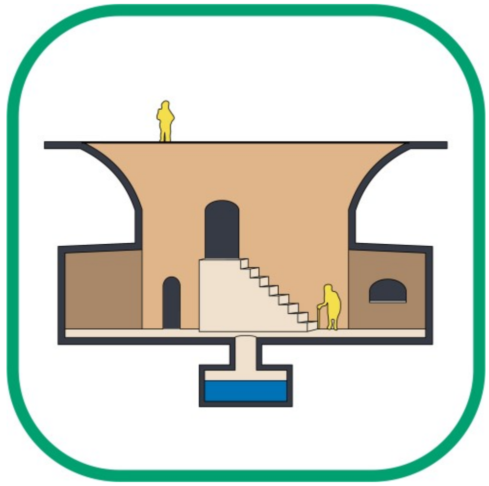

Figure 35: Indigenous subterranean structure.

While the many of the attributes of the previously outlined form are similar within fully subterranean structures, the greatest benefit of fully submerged a structure is natural wildfire movement is unlikely to threaten the roof, walls, or apertures of such forms as they are either sealed or concealed underground. Indeed, the combined risks of embers, flames, and ambient heat are negated by the recessed quality of the space, which would withstand a wildfire event with inhabitants safe from the danger blazing through the landscape. With the addition of a protective system of window, door, and lightwell coverings and the risk of external fire is virtually zero. Beyond concerns over wildfire, the performance of underground structures sited in appropriately dry environments would require a reduced level of upkeep due to decreased exposure to sun, wind, and rain, while offering excellent insulation and a sheltered sense of safety (Jewell, 2017). If initial resistance to change and novelty could be overcome, the potential for fully and semi-subterranean forms to dramatically improve the survival rate of structures in fire-dependent ecosystems is clear.

Figure 36: Sectional view of burrowed home indicating ground and topography.

DISCUSSION

Limitations

While many of the limitations imposed on the design of communities, landscapes, and structures located within fire-dependent ecosystems such as San Luis Obispo are imposed by existing zoning, building codes, and conventional perspectives, the clear limitations of the outlined proposals result from the unpredictable behavior of wildfire, and the refusal to expect fire events that are meant to happen.

Beginning with community design, the perception that single-family residential structures are a near-sacred right for middle class Americans has resulted in issues ranging from sprawl to the reluctance to increase urban densities that are far easier to defend against wildfire. Added to this is an environmental review policy in California and elsewhere that would greatly encumber efforts to create large-scale earthworks such as a one hundred foot firebreak or a reservoir (Einstein et al., 2020). In addition, the permitting of cyclical grazing and prescribed burns can be slow and energy-intensive, even while they remain one of the cheapest means of preventing uncontrolled wildfire. Plus, many property owners would be outraged by the idea that they cannot rebuild a conventional structure following the loss of an existing building due to wildfire. While building code does dictate the standards for new construction, some places may be too fire-prone for habitation (Williams, 2020).

Second to community form, the limitations of landscape management policies aimed at fire protection include the fierce independence of many Americans, and the preeminence given to the idea that an individual freedom and the infallibility of property rights. The result is a smattering of property owners who place their own interests ahead of the greater good. Behavior such as this can render the defensible space of one individual useless due to the actions of their neighbor.

The last of the limitations posed by the process of firesafe design can be found in the structural forms suggested here. While most of the proposed interventions are proven means of fire resilience, the partially and fully subterranean forms could be met with objections from planners, code enforcers, and community members within many municipalities. Beyond these potential limitations, the fact remains that the initial desire to explore elevated forms was quickly stifled by the simple fact that an elevated structure faces increased risks of destabilization due to heat exposure at the level of a form's footings, as well as the underside of floorplates. Also, an elevated structure surrounded by fire poses a deadly risk to inhabitants who – if sheltering in place – could easily perish due to smoke inhalation or heat exposure. This reality is something that was wrestled with repeatedly, as the question of whether a structure could be designed to improve with fire exposure was quickly snuffed by the simple fact that metal, concrete, earth, and wood are all made weaker with recurring exposure to high heat. In the end, the forms presented are limited by reality rather than the creative exploration of possibilities.

Findings

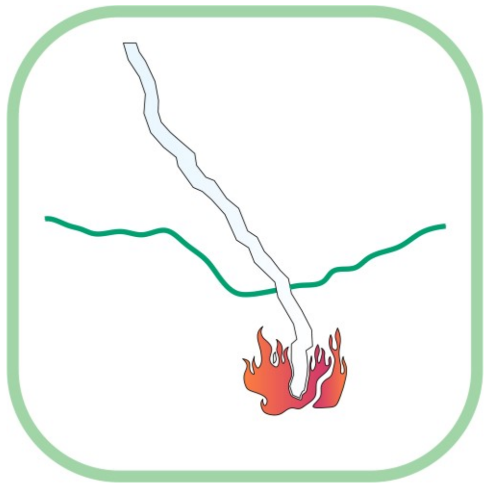

Figure 37: Lightning strike.

As outlined above, the range of community, landscape, and form-based issues examined in relation to wildfire preparation within the wildland-urban interface of southern California are varied and specific to each ecosystem, municipality, site, and structure. With initial exploration of biological and indigenous adaption to such environments, the possibility of discovering a subtle truth seemed likely, as nature continually offers ingenious ways to handle human problems. As this exploration progressed into the realm of contemporary activity, it proved obvious that the greatest inhibition to real change in the way people inhabit fire-reliant ecosystems is a reluctance to embrace change, combined with obliviousness to the dynamic process cleansing and rejuvenation that fire offers within these landscapes. Beyond the failings of human nature, the ultimate moment of revelation, the expected ‘lightning strike,’ never seemed to come. Instead, an acceptance of the complexity of the environment, communities, and inhabitants of these places was gained. While there is no simple solution, there are many. Hopefully, the exploration of these ideas serves as a catalyst for continued questions and answers to how humans may better interact with the inevitability of wildfire.

CONCLUSION

Even as wildfires grow in scale and frequency in the United States and abroad, the cause of such events are argued over more often than the possible solutions to this drastic loss of life, community, and infrastructure. Indeed, burn bans and total fire suppression are still the prescriptive norm in most municipalities, even as ecologists have come to recognize the range of environmental benefits offered by fire within fire-dependent ecosystems. As human settlement continues to grow, pushing ever deeper into places where wildfire is meant to happen, the risk of loss continues to increase. Add to this a changing climate where winds, rainfall, and vegetative fuels are increasingly unpredictable, and the question must be postulated of how architecture, landscape management, and urban design might be used to shape fire-adapted communities situated within fire-dependent ecosystems.

Figure 38: Herbivores mitigate wildfire every day.

Looking to the plants, animals, and indigenous people that came to successfully inhabit these spaces for millennia, a variety of observations related to biomimicry and indigenous design were made and combined with conventional standards of community, landscape, and building design assessed through the analysis of precedents. Based on this, a series of design implementations were proposed, tested, and applied on a variety of scales. The result is a synthesis of planning, policy, and design approaches that might be incorporated to varying degrees by stakeholders on the municipal, neighborhood, or individual level.

Based on these findings, communities, properties, and structures may truly be designed to withstand wildfire within fire-dependent ecosystems. Whether based on the inspiration form and egalitarianism of Australian wombats and their burrows, or the ingenious design of leaf stomata able to sense heat and exhaust that might compromise their functionality, or the adaptive skills of indigenous people that saw fire not as a risk, but as medicine, the lessons contained in this thesis point to a possible future in which contemporary populations are able to mitigate their losses while allowing ecosystems to function as designed.

BIBLIOGRAPHY

Jeffery, Tom, Denise Moore, Frances Calgiano, and Rhea Turakhia. "The 2019 Wildfire Risk Report." CoreLogic. Accessed February 26, 2020. https://www.corelogic.com/insights/wildfire-risk-report.aspx.

Russell, Pam Radtke. "California Towns Rebuild After Wildfires With Resilience in Mind." Engineering News Record RSS, Engineering News Record, 30 Apr. 2019, www.enr.com/articles/46681-california-towns-rebuild-after-wildfires-with-resilience-in-mind.

Cummins, Eleanor. "Fire-Proofing California's Homes Is Possible-but at What Cost?" Popular Science. Popular Science, November 25, 2019. https://www.popsci.com/story/environment/fireproof-house-california/.

Paveglio, Travis B., et al. "Exploring the Influence of Local Social Context on Strategies for Achieving Fire Adapted Communities." Fire, vol. 2, no. 2, 2019, p. 26., doi:10.3390/fire2020026.

Kasler, Dale, and Phillip Reese. "'The Weakest Link': Why Your House May Burn While Your Neighbor's Survives the next Wildfire." Sacbee, The Sacramento Bee, 11 Apr. 2019, www.sacbee.com/news/california/fires/article227665284.html.

Westervelt, Eric. "After Paradise, Living with Fire Means Redefining Resilience." NPR. NPR, May 29, 2019. https://www.npr.org/2019/05/29/724407043/after-paradise-living-with-fire-means-redefining-resilience.

The New Wild: Why Invasive Species Will Be Nature's Salvation. By Fred Pearce. Boston (Massachusetts): Beacon Press. 2015, pp. 144–145.

Benyus, Janine. "What Is Biomimicry?" *Biomimicry.org*, Biomimicry Institute, 2021, biomimicry.org/what-is-biomimicry/.

Smith, Alistair M. S., Crystal A. Kolden, and David M. J. S. Bowman. "Biomimicry Can Help Humans to Coexist Sustainably with Fire." Nature Ecology & Evolution 2, no. 12 (May 2018): 1827–29. https://doi.org/10.1038/s41559-018-0712-2.

Nimmo, Dale. "Animal Response to a Bushfire Is Astounding. These Are the Tricks They Use to Survive." *The Conversation*, 20 Nov. 2020, theconversation.com/animal-response-to-a-bushfire-is-astounding-these-are-the-tricks-they-use-to-survive-129327.

"Trees." National Parks Service, U.S. Department of the Interior, 23 Nov. 2020, www.nps.gov/havo/learn/nature/trees.htm.

Griggs, Mary Beth. “A Tree That Could Stop Wildfires.” *Popular Science*, 2 Sept. 2015, www.popsci.com/cypress-trees-are-resistant-to-wildfires/#:~:text=In%20a%20recent%20study%20published,to%20wildfires%20in%20the%20future.&text=But%20only%201.27%25%20of%20the,Bernab%C3%A9%20Moya%20told%20BBC%20Mundo.

Koksal, Kubra, Jim McLennan, Danielle Every, and Christopher Bearman. 2019. “Australian Wildland-Urban Interface Householders’ Wildfire Safety Preparations: ‘Everyday Life’ Project Priorities and Perceptions of Wildfire Risk.” International Journal of Disaster Risk Reduction 33 (February): 142–54. doi:10.1016/j.ijdrr.2018.09.017.

“Our Common Future.” *World Commission on Environment and Development*. Oxford University Press, 1987.

Lake, Frank K., and Amy Cardinal Christianson. “Indigenous Fire Stewardship.” Encyclopedia of Wildfires and Wildland-Urban Interface (WUI) Fires, 2019, 1–9. https://doi.org/10.1007/978-3-319-51727-8_225-1.

“Rethinking Our Resilience to Wildfire.” Global Warming Focus, September 16, 2019. Gale Academic OneFile.

Kolden, C.A., and Henson, C. A Socio-Ecological Approach to Mitigating Wildfire Vulnerability in the Wildland Urban Interface: A Case Study from the 2017 Thomas Fire. Fire 2019, 2, 9.

“Mitigating Wildfire Vulnerability.” *U.S. Fire Administration*, 16 July 2019, www.usfa.fema.gov/current_events/071619.html.

Sturtz, Rachel. “Rethinking Our Resilience to Wildfire.” CU Denver News, 23 Sept. 2019, news.ucdenver.edu/rethinking-our-resilience-to-wildfire/.

Aliento, Willow. “How to Design Your House for Fire Resistance and Sustainability.” The Fifth Estate, 21 Jan. 2020, www.thefifthestate.com.au/innovation/residential-2/how-to-design-your-house-for-fire-resistance-and-sustainability/.

Milne, Murray. University of California, Los Angeles, 2020, pp. 1–3, *Designing Your Home to Survive Wildfires*.

Gibson, Scott. “Building to Survive in Wildfire Country.” Fine Homebuilding, 19 Apr. 2018, www.finehomebuilding.com/2018/02/27/building-survive-wildfire-country.

Abadi, Mark. “An Engineer Spent 15 Years Fireproofing His California Home. Here's Why His House Was the Last One Standing after a Devastating Blaze Last Year.” *Business Insider*, Business Insider, 12 Feb. 2020, www.businessinsider.com/california-fire-fireproof-home-sonoma-county-kincade-2020-2.

Williams, Mike. "Fear of Wildfires Inspires Forward-Thinking Communities." *Rice News*, 22 Jan. 2020, news.rice.edu/2020/01/22/fear-of-wildfires-inspires-forward-thinking-communities-2/.

Hallegatte, S., Ranger, N., Mestre, O. et al. Assessing climate change impacts, sea level rise and storm surge risk in port cities: a case study on Copenhagen. Climatic Change 104, 113–137 (2011). https://doi.org/10.1007/s10584-010-9978-3

"San Luis Obispo Travel." *Lonely Planet*, 8 Sept. 2019, www.lonelyplanet.com/usa/california/san-luis-obispo.

"Visit Mission San Luis Obispo De Tolosa." *Mission San Luis Obispo De Toulosa*, Old Mission Parish, 23 Oct. 2020, missionsanluisobispo.org/visit/#history.

City of San Luis Obispo's Cultural Heritage Committee. City of San Luis Obispo Historic Preservation Program Guidelines, City of San Luis Obispo, 2010, pp. 4–6.

Murphree, Tom, Emily Szasz, Kellen Jones. "Santa Ana Events in California: Global Scale Teleconnections and Potential Subseasonal to Seasonal Predictability." *Science and Technology Infusion Climate Bulletin NOAA's National Weather Service 43rd NOAA Annual Climate Diagnostics and Prediction Workshop*, 2018.

"Student Life." *Visit Cal Poly*, California Polytechnic State University, 2021, visit.calpoly.edu/student/student-life.html.

"Fire Resistant Windows." *FIRESafe MARIN*, 20 Mar. 2015, www.firesafemarin.org/home-hardening/windows#:~:text=Install%20window%20screens,will%20not%20keep%20flames%20out.

Howard, Brian Clark. "How Sequoias Survive Wildfires." *Science*, National Geographic, 10 Feb. 2021, www.nationalgeographic.com/science/article/130826-giant-sequoias-yosemite-rim-fire-forestry-science.

Peris Mora, Eduardo. "Life Cycle, Sustainability and the Transcendent Quality of Building Materials." *Building and Environment*, vol. 42, no. 3, 2007, pp. 1329–1334., doi:10.1016/j.buildenv.2005.11.004.

Mitchell, Paul. "Bushfire Resistant Houses." *Shelter Space: Australian Earth Sheltered House Designers*, 2020, shelterspace.com/bushfire-resistance.

Erdem Yücel, and Solak Tülin. *Underground Space Use Analysis of the Past and Lessons for the Future*. A.A. Balkema Publishers, 2005.

Jewell, Nicole. “This Earth-Sheltered Australian Hobbit Home Stays Cozy All Year.” Inhabitat Green Design Innovation Architecture Green Building, 28 July 2017, inhabitat.com/this-earth-sheltered-australian-hobbit-home-stay-cozy-all-year/.

Einstein, Katherine Levine, et al. *Neighborhood Defenders: Participatory Politics and America's Housing Crisis*. Cambridge University Press, 2020.