Memory, Place, and Firefighting
Using a Typology of Floor Plans as a Wayfinding Tool in Smoke

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A thesis
submitted in partial fulfillment of the
requirements for the degree of

Master of Science

University of Washington

2022

Committee:

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Program Authorized to Offer Degree:
Department of Architecture

University of Washington

ABSTRACT

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Wayfinding within any environment is contingent on the dynamic interaction between perceptual and cognitive processes. The kind of wayfinding firefighters perform is purpose-driven and time-sensitive. What makes firefighters unique in the history of human wayfinding practice is not the threat of physical harm, or the need to be sensitive to subtle environmental cues, rather it is the speed at which firefighters must orient to the environment and then navigate with impaired vision. There is a need to enhance firefighters' understanding of the environment they operate in most-often. What is necessary, but does not currently exist, is a guide that structures how firefighters recognize, interpret, and communicate about houses. Such a guide would describe standard house types and allow firefighters to make more accurate predictions about the interior spatial configurations. The repetitive character of houses can be codified and used to improve firefighters' wayfinding practices. This thesis examines how a typology of historic and contemporary residential floor plans (which are abstract representations of the most-common houses in the United States) are a valuable mnemonic tool for firefighters. Research into this aspect of architecture is placed within the context of firefighting and accounts for the experience of firefighters who are tasked with finding their way in toxic smoke to rescue those trapped or incapacitated — *as fast as possible*.

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Sheri Hemrick photo.

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ACKNOWLEDGMENT

In 2020, I approached Department of Architecture faculty members Jeffrey K. Ochsner and Alex T. Anderson, Ph.D. with this thesis idea. I am thankful and honored that these two exceptional scholars agreed to guide the effort. It benefited from their expertise in many ways, but their thoughtful and comprehensive edits, comments, and suggestions helped bring the story to life. I thoroughly enjoyed the time we spent working together. They exemplified an effective approach to the craft of research and writing about architecture I hope will shine through in the following pages. There is no doubt the manuscript is better because of their effort.

I want to sincerely thank architect and historian Thomas C. Hubka, whose exhaustive research and expertise regarding American housing is central to the thesis. Professor Hubka graciously spent many hours teaching me about houses and patiently answered all my questions. He taught me a systematic method to orient to the stable, predictable features of houses.

Harvard Professor John R. Stilgoe, whose summer course I had the good fortune to attend, encouraged me to think critically about the built environment, to "look sideways," and to put words to what I see. I took his advice to heart. This is my attempt to be thoughtful and deliberate about describing a problem I see.

I am grateful for the opportunities afforded by the Department of Architecture. Faculty encouraged me to share my firefighting experience in the university setting. This collaboration helped the thesis idea develop into something firefighters *and* architects can use. My friends and colleagues Aaron Fields, Jimmy Watts, Nate Jamison, Karl Waite, Matt Lujan, Jason Asmus, and Josh Schmidt offered thoughtful critique and suggestions to improve the manuscript.

Lastly, I would like to extend a heartfelt thank you to my family for their unconditional, unequivocal, and loving support. This arduous endeavor would not have been possible without it.

For Charlotte and Krista.

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PREFACE

"The question is not what you look at, but what you see."[1]

– Henry David Thoreau

In the 1990s, I was a frequent visitor to the neighborhood firehouse near my childhood home in Pueblo, Colorado. I remember asking the firefighters to allow me to wear their protective equipment. With some persistence on my part, they would oblige. As they draped a coat over my tiny frame and placed a leather helmet on my head, I was transported to another world. Their bunking gear smelled of smoke and sweat. The breathing apparatus, the tank of air that allows them to breathe clean air inside burning buildings, was heavy. I remember the "rush" I felt when an alarm came in, the bell rang and set into motion a performance unlike anything I had seen before. I was hooked. Sometimes I catch a whiff of smoke after a fire, inside my own firehouse today and it takes me back to the days when I imagined crawling down smoky hallways to fight fires like those firefighters I met all those years ago. The tempo of a firefighter's life is punctuated by memories like these; by the sights, smells, sounds, exhilaration – and the heaviness – of the experience.

Firefighters participate in the production of a unique kind of local knowledge that is difficult to articulate and rarely noticed or studied by serious scholars. Much of what firefighters know is hard to pin down. It is clear that firefighting has created a unique "theory of knowledge" on cities and the buildings in them. A firefighter's experience represents a distinct way of knowing a place, through all the senses, through actions on and inside burning houses, and through stories firefighters tell about emergency work.

The studio education I received in undergraduate architecture school from 2006-2010, and today in graduate school, trained me to visualize and communicate, to pull things apart and understand how the parts fit together. I learned to see in plan, section, elevation, and perspective. As I have discovered, this is an essential skill in firefighting. Studio concepts came to life inside burning buildings. The view I have from the end of a hoseline, facing a fire, is a perspective very few architects get. Likewise, few firefighters receive training in an architecture school. Emergency calls, fires, experimental training fires, and training in buildings scheduled for demolition have allowed me to examine the built environment like in an anatomy lab. This experience helped facilitate cognitive leaps on the fireground – I have learned to see patterns, associations, and order where none were perceived before. Only twelve years into my career as a professional firefighter, have I realized just how valuable this education has been.

I am able to speak about how firefighters come to know what they do in part because of my training but also from my experience educating firefighters in the Nozzle Forward program. The Nozzle Forward is a firefighter education program taught nationally by Aaron Fields and a cadre of instructors, including myself. In the last 12 years, the program has instructed over 45,000 firefighters. It is the only program to have taught firefighters in every region of the United States and in multiple Canadian provinces. The course is a point of conduction between multiple disciplines including history, brain science, architecture, and firefighting. As a training program and methodology, the Nozzle Forward has helped me recognize, document, and articulate how firefighters come to know this environment. The program has afforded me many opportunities to study how firefighters are educated.

This thesis represents an effort to make sense of my experience and to investigate a simple question – how do firefighters find their way in dark smoke? This question can be reframed to ask – how do firefighters make sense of the floor plan in a zero-visibility environment? In researching this question, I have come to realize that sensemaking is a fragile construction and that wayfinding is a dynamic, whole-body effort.

During a fire, firefighters must quickly make sense of an overwhelming, multi-modal flow of information. From this complexity, firefighters must separate *things that happen* from the *things that matter*. We often do this in zero visibility, enveloped in toxic smoke. This is no simple task. Without visibility, we essentially operate by feel. Without a framework that helps one to stay oriented and calm, it's easy to get lost (literally). Not only do we rely on environmental cues, we also rely on memories. Memories are the cognitive structural elements that firefighting efforts are based on. These memories are situated yet portable, and to a large extent reusable.

There is order, structure, and hierarchy in the built environment, but firefighters are not taught a systematic method to recognize that order. Addressing this gap is the motivation behind this thesis. I will argue that the structure of firefighting knowledge is shaped by the regular geometric order of the built environment to an extent not previously understood. Firefighting depends on recognition of cues, even in smoke. Sensemaking, then, starts with a more comprehensive understanding of the way firefighters experience this environment, which includes seeing (sometimes), smell, hearing, and "feel." This thesis is my small contribution to a body of knowledge assembled by those who come to the aid of strangers when the alarm is sounded. It is dedicated to those who must find their way in dark smoke.

Author, circa 1993. Robert and Rebecca Legan photo.

ENDNOTES (PREFACE)

1 Henry David Thoreau and Damion Searls, ed. *The Journal, 1837-1861*. (New York: New York Review Books, 2009), 65.

INTRODUCTION

"It is hard to know what to do with all the detail that rises out of a fire. It rises as thick as smoke and threatens to blot out everything — some of it is true but doesn't make any difference, some is just plain wrong, and some doesn't even exist, except in your mind, as you slowly discover long afterwards. Some of it, though, is true — and makes all the difference."[1]

– Norman Maclean

Problem Statement

Firefighters require a perceptual and cognitive framework that reduces experience of chaos during a fire — a framework that facilitates recognition and accurate interpretation of critical environmental characteristics and aids wayfinding, even in smoke. During their work, firefighters collect a mental library of sights, sensations, knowledge, and episodic memories related to the built environment — especially of fires in houses, but this is not systematized in ways that consistently aid them in future firefighting situations. This thesis considers how the repetitive character of these residences, as experienced by firefighters, can be codified and used to improve training for wayfinding in smoke-filled houses. It does so primarily by examining how a typology of historic and contemporary house floor plans can serve as a firefighting tool. Research is placed within the context of firefighting and accounts for the experience of firefighters who are tasked with finding their way in toxic smoke to rescue those trapped or incapacitated — *as fast as possible*.

Research Objectives, Questions, and Scope

The primary objective of this thesis research is to establish a pragmatic framework to improve a firefighter's visuo-spatial literacy using a typology of historic and contemporary house floor plans. Its aim is simple — to save lives by improving firefighters' understanding of houses on fire and their ability to wayfind in dark smoke.

In his book *The Image of the City* (1960), American urban planner and theorist Kevin Lynch is widely thought to have introduced two concepts into the modern architectural lexicon: "wayfinding," as a single word, and "legibility."[2] Lynch examined the "environmental image" of three cities, as constructed in mind by those who live there.[3] He tried to understand the ease with which the various parts of a city "can be recognized and can be organized into a coherent pattern."[4] To put this another way, Lynch was concerned with a city's "legibility," or the clarity of its built patterns.[5] The "legibility" of an environment depends on a number of aspects, some of which will be studied in this thesis. Finding one's way, from one place to another, however, is not new, nor is it a concept and practice specific to humans. What made Lynch famous was the connection he made between the "legibility" of the built environment and one's ability to find their way, or to "wayfind," within it. This thesis uses Lynch's groundbreaking research as a semantic framework.

Wayfinding, as defined by Lynch, is the "consistent use and organization of definite sensory cues from the external environment."[6] Expanding on Lynch's definition, noted Geographer Reginald Golledge defines *wayfinding* as "the process of determining and following a path or route between an origin and a destination. It is purposeful, directed, and motivated activity."[7] These definitions are supportive of one another, contextually appropriate to firefighting, and will be used throughout the thesis. Using cues from the environment and from memory, firefighters determine a path to locations inside burning buildings, and back out. While this research differs in purpose, in scope, and in scale from Lynch's, a similar logic will be applied to understand how and why different types of houses affect firefighters' ability to wayfind in smoke. Wayfinding is ubiquitous in human experience. It can be thought of as an individual or group problem-solving and decision-making process, one that includes *orientation*, *navigation*, and *locomotion*. For clarity, the term "wayfinding" or the phrase "to wayfind" will be used throughout the text, as a noun and as a verb. This is a purposeful and necessary deviation from standard grammatical convention.

In *The Image of the City,* Lynch created a "shorthand" method for studying and describing city patterns. This thesis will do something similar, but for houses. In seeking to make houses more "legible" to firefighters, this thesis investigates the contents of firefighters' mental "images" in a manner similar to Lynch. Relating one's mental "image" of the environment to wayfinding, Lynch writes that

> The strategic link is the environmental image, the generalized mental picture of the exterior physical world that is held by an individual. The image is the product both of immediate sensation and of the memory of past experience,and is used to interpret information and to guide action.[8]

According to Lynch, to be useful, one's "image" of the environment must have a number of specific qualities. First, "it must be sufficient, true in a pragmatic sense…whether exact or not, must be good enough to get one home."[9] Second, it should include a "surplus of cues so that alternative actions are possible and the risk of failure is not too high."[10] Third, one's mental image should be "open-ended, adaptable to change, allowing the individual to continue to investigate and organize reality."[11] Lastly, "it should in some measure be communicable to other individuals."[12] Human perceptual and cognitive mechanisms have been shown to be so adaptable "that every human group can distinguish the parts of its landscape, can perceive and give meaning to significant detail. This occurs no matter how undifferentiated that world may seem to an outside observer."[13] To understand how this is possible, one must study the regularity, or the patterns, of the environment in question.

In working to understand how different types of houses influences firefighters' ability to wayfind in smoke, the thesis draws from different academic disciplines and integrates multiple lines of inquiry. The following premises establish the theoretical framework behind using a typology of houses to help firefighters wayfind in smoke.

Premise 1: A typology formalizes a methodological and theoretical approach to studying the design of houses in an historical and practical context.[14]

Premise 2: Typologies classify houses in a manner that allows for recognition and naming, thus providing firefighters with an "interior-specific, history-specific, and contemporary design-specific vocabulary."[15]

Premise 3: Typologies should be used as the foundation for interdisciplinary research into the wayfinding practices of firefighters because a typology accommodates "the curricular values of various academic programs and the expertise of a range of scholars."[16] In this case of this thesis, brain science, architecture and firefighting research and findings can inform firefighter practices improving decision-making and potentially save lives.

Premise 4: There are useful geometric patterns in the configuration of houses that could assist firefighters tasked with wayfinding in smoke. The interior spatial configurations of houses have been shown by architectural historians to follow reiterative patterns. Firefighters are not currently taught to recognize these patterns.

Premise 5: The catalog of house types proposed in this thesis is a means to make tacit knowledge firefighters have explicit and more usable in the urgent wayfinding scenarios firefighters encounter.

This thesis supports its argument by drawing from research in brain science, human spatial navigation, and architectural history. It uses information from these fields to suggest how to enhance training for wayfinding in smoke and to improve existing firefighting practices. In order to do this, the thesis seeks to accomplish three objectives:

1. To identify relevant information, simplify complex concepts, combine useful research, and define applicable methods reported in literature from the following fields: brain science, human spatial navigation, architecture, vernacular architecture history, and educational pedagogy. The thesis pursues the following related questions:

    - What other research, specifically outside the fire service, could inform and possibly improve existing wayfinding practices in firefighting?

    - How have other cultures in human history oriented to and then navigated in dangerous environments?

    - What technological developments influenced wayfinding practices in the American fire service?

    - How are firefighters currently taught to wayfind in smoke?

2. To introduce firefighters to the proposed typology of floor plan types. This emphasizes the distinctive internal (floor plan) and external (form) characteristics in single-family houses, which constitute – nearly 70 percent of the residential fires in the United States.[17] In moving toward this goal, the research followed these questions:

    - What kinds of information (visuo-spatial, historical, contextual, environmental, etc.…) do firefighters need in order to make decisions related to wayfinding in smoke?

    - How are firefighters taught about the buildings inside of which they orient to and navigate under the pressure of a fire emergency?

    - Do firefighting textbooks and educational frameworks currently in use identify any of the house types? Are there any exemplary pedagogical precedents in firefighting, or other fields of study?

    - Are there useful existing typologies of residential houses? If not, can they be created?

    - How well, if at all, can firefighters identify the most-common floor plan types in the United States?

3. To integrate concepts from brain science research into a visuo-spatial framework that explains how mental processes — perceptual, emotional, or motor — inform firefighters' decisions, actions, and sensemaking abilities during acutely-stressful and sometimes dangerous work related to wayfinding inside a burning house. Investigation of research from these fields helped address these questions:

    - How do firefighters come to know this environment?
    - How do firefighters make sense of this environment?
    - How is this knowledge organized, accessed, and used in action?
    - What tools do firefighters use (literal, cognitive, linguistic, visual representative, or otherwise) to help them navigate in smoke and make sense of residential spaces when they are obscured by smoke?
    - What happens when the brain uses confusing, ambiguous, or false information?
    - What methods do firefighters use to transmit experience? Can these methods be improved?

At a fire, firefighters typically forecast potential victim and fire locations then execute an informed search without a full understanding of the environment they navigate, often in zero visibility. Firefighters are expected to *know the way* to reach two separate, but related locations inside the building — the location of where people are trapped and the location of the fire itself. Within a few seconds of arriving on scene, firefighters must be able to orient to, and make sense of, any structure in the built environment. They make rapid inferences, or "educated guesses," sometimes with life-and-death implications.

Firefighters are tasked to respond to fire emergencies in all types of occupancies. This requires that firefighters have detailed knowledge about a wide range of patterns in the built environment patterns. For example, occupancy, use, interior configuration, materiality, structure, and construction assemblies. However, to limit the scope of research, this thesis only focuses on residential floor plan types and the experiences firefighters have fighting fires in detached, single-family houses. These are the buildings that firefighters encounter most-often. The visuo-spatial inquiry framework developed in this document, however, can be applied to residential structures of all types (for example, to rowhouses or apartment buildings), and to a large extent to other occupancy types (for example, types of commercial buildings).

This thesis presents a catalog of house types that equips firefighters with a "shorthand" graphic language, one that is interdisciplinary in nature, to be used in situations where words fail to effectively communicate spatial characteristics.[18] Of particular importance in this thesis is the floor plan. This thesis will use the definition of the *floor plan* from Marc Trieb's *Drawing/Thinking* – "an abstract, commensurable representation of a ground plane that allows us to study the interior space and scale of a building."[19] This graphic convention is a "means to discover the relationship between the qualities (dimensions, proportions, scale, construction, materials, and so on) and life within these urban spaces."[20] Special emphasis is made throughout that firefighters be taught to recognize the relationship between the *exterior* of the house and the *interior* floor plan. Although the thesis emphasizes the floor plan, the heart of this thesis is the organization of three-dimensional visuo-spatial information in a manner that supports firefighters' wayfinding in smoke.

Practical Implications

When one can see, orientation, navigation, and locomotion are relatively straightforward because cognitive demands can be off-loaded to the environment. Integration of sensory and perceptual information happens largely unconsciously. However, in a fire, upon entering a burning house, the firefighter is, to a certain extent, blind. In this environment, firefighters depend heavily on spatial mental models adapted to navigation without sight which places a high demand on their perceptual and cognitive processes. Conditions inside a burning house often prevent the use of familiar visual references. Time pressure, the urgent nature of the search, and physiological reactions to acute stress affect wayfinding capacity. The smoke and fireground noise, heavy protective clothing that completely encloses the body, and sporadic radio communication, regularly shift a firefighter's attention in multiple competing directions. Movement in smoke is slowed greatly by the time it takes the nervous system to process sensorimotor inputs. Repetition teaches firefighters to unscramble the identities of things in dark smoke, but this uses valuable time and directs the limited attentional resources away from orientation and fire suppression motor programs. Firefighters often default to well-rehearsed, or habituated, responses but find themselves unaware of how close they are to disorientation on a regular basis. Smoke obscures the environment in ways that have profound effects one's ability to stay oriented and navigate through a burning building. Smoke is toxic and kills quickly, painfully.

This thesis proposes the development of "seeking-out-routines" and flexible thinking dispositions that allow information to be obtained quickly from the environment in order to help firefighters recognize spatial patterns, retain good situational awareness, and ultimately navigate more effectively.[21] This thesis proposes a type of field reconnaissance firefighters can use immediately, with little formal training *before* the fire. The proposed catalog of house plan types provides a number of "templates" and simple heuristics that can be used to inform decisions (or thrown out if need be) *during* the fire. And the catalog acts as a storytelling and diagrammatic adjunct *after* the fire – helping capture firefighting experience in ways words cannot.

The catalog seeks to limit the possible variables firefighters can expect to encounter. It emphasizes a system of *cues*, *expectancies*, *goals*, and *typical actions* for wayfinding inside burning houses. Single-family houses in the United States share more in common than is generally acknowledged by the American fire service. Repetition of well-known house types and plans occurs nationwide, thus offers a stable foundation. This means that most people are familiar with at least a few of the typical floor plans and associated patterns, even if they cannot easily articulate them. The thesis develops a series of templates that describe how different house types are organized and why houses warrant sustained, detailed scrutiny.

Pedagogical Implications

Firefighters are not taught using learning models that address the human and environmental factors implicated in wayfinding. In their current form, training models used by fire departments, large and small, throughout the United States fail to integrate valuable research from brain science, human spatial navigation, architecture, vernacular architecture history, and adult education fields of study. This thesis seeks to begin to remedy this failure.

The catalog of house plan types will serve to structure expectations; it establishes a descriptive naming convention; offers a basis for collecting and conveying knowledge and experience; and it provides critical historical context for the stories firefighters share about their experience. Firefighters already receive repeated exposure to these common floor plans due to the nature of emergency work; they simply need to be taught what to look for to recognize each of them. This document represents a focused effort to shift the educational paradigm in an industry that does not prepare firefighters well to recognize, interpret, and respond to fires in a dynamic and increasingly complex residential built environment. A framework for understanding houses on fire should not require complicated mental constructions.

Research Methodology

"Wayfinding in Smoke" builds on a typology of residential houses outlined by architect and vernacular architecture historian Thomas C. Hubka in *Houses without Names: Architectural Nomenclature and the Classification of America's Common Houses.*[22] To expand

and orient this toward firefighting training and practice, information was collected from an extensive literature review, quantitative field reconnaissance of house types in Seattle (and other cities), first-person accounts of firefighting experience, qualitative survey responses from firefighters in the United States and Canada, and archival research. The proposed typology of historic and contemporary floor plans represents theoretical and practical common ground joining multiple areas of academic study.

Over the course of their careers, firefighters are afforded unique access inside many thousands of houses, including many on fire. This valuable experience is unevenly documented. Although there are some accounts in writing, with pictures, or with visual representations, this information has not been collected or codified. Gained from time spent inside houses of all eras and types, this experience and spatial knowledge is extremely valuable, but little academic research exists documenting firefighting efforts in single-family houses. To the best of this researcher's knowledge, no research exists connecting wayfinding to common floor plan types as developed by Hubka (or anyone else). Research for this thesis proceeded through the following phases:

Phase 1 – Preliminary research and literature review

Phase 2 – Field-reconnaissance

Phase 3 – Documentation (photographs, drawings, diagrams)

Phase 4 – 2021"Wayfinding in Smoke" survey

Phase 5 – Archival research

Phase 6 – Integration

Survey Research

Research in *Phase 4* included a 32-question survey. In the survey, administered nationally in 2021, respondents were asked to answer questions about their experience wayfinding in smoke using Likert Scale responses, as well as open-ended questions allowing written responses. (The University of Washington Human Subjects Division (HSD) reviewed the "Wayfinding in Smoke" survey (STUDY00013164). HSD determined that the proposed study is human subjects research that qualifies for exempt status (Category 2). Study approved on April 23, 2021.

Participants in this survey were recruited via the Nozzle Forward website and social media pages (the Nozzle Forward is a firefighter training organization), via personal contact and email from the Seattle Fire Department, and via email from the ranks of other fire departments outside Seattle. [23] Prospective participants were advised that the study would involve answering questions about wayfinding practices inside a building on fire. Survey data are completely anonymous, and participation was voluntary. Participants could withdraw from study at any time. Participants received no compensation for their participation. This survey collected responses from firefighters regarding the wayfinding mechanics, orientation and navigation in smoke, and spatial memory and understanding. Nearly 59,000 firefighters accessed the Facebook post. 2,896 firefighters representing 49 American states and six Canadian Provinces responded to the survey. 51% of those firefighters (or nearly 1,600 firefighters) completed all sections of it. Some questions generated nearly 1,000 narratives and descriptions of varying length, about firefighters' experience navigating in smoke.

The survey was designed to capture data about an experience that is rarely documented and studied by serious scholars. The survey likely represents the first recorded national survey of firefighters' experience navigating in smoke.

Review of Literature

"Memory, Place, and Firefighting" is based on my own experience as a professional firefighter and fire service educator, who is also trained as an architect. The research grew out of a simple question I asked other, more senior firefighters – *how do firefighters find their way in smoke?* Reports compiled by the National Institute for Occupational Safety and Health's (NIOSH) Fire Fighter Fatality Investigations and Prevention Program often cite *disorientation* as a contributing factor in firefighter deaths.[24] Losing orientation contributes to a loss of sensemaking capability in an environment where firefighters regularly encounter rapidly changing fire conditions, little (or no) visibility, and operate on a limited supply of air. Some firefighters made wayfinding in smoke seem so easy, others, not so.

After every fire, I scrutinized my own training, experience, and understanding of the processes behind human wayfinding ability, or in some cases, inability. This thesis represents an inquiry spanning 13 years of firefighting, in two busy, urban fire departments in the United States, nearly 10 years as a fire service educator, and six years as a student of architectural practice, along with many hours reading and questioning. I looked to a number of sources for answers to my questions. The reader will find primary research extensively cited from books and scholarly journals, along with personal anecdotes throughout the document, but it is important to review some specific examples first, before one ventures into the body of this thesis document. These were the sources and academic research that functioned as my guides. Each one represents a theme woven into the thesis that is supported by other academic research.

Studying the nature of firefighters' emergency work at a burning building engages a number of fields of academic research – firefighting, architecture, history, brain science, human performance, wayfinding, storytelling, and others. Unfortunately, however, very little research into firefighting practices exists. The most notable example is the 1988 study of firefighters' decision-making on the fireground by Gary A. Klein, Roberta Calderwood, Anne Clinton-Cirocco, and their Systems Research Laboratory. Results presented in the *Rapid Decision Making on the Fire Ground* technical report are the basis for the Recognition Primed Decision-Making Model (RPD), a model commonly cited by firefighters. It describes how firefighters "rapidly integrate information from a large array of accumulated experiences to size-up a situation and select a course of action through mental simulation."[25] Norman Maclean's *Young Men and Fire*, is the epic tale about the deaths of 13 smokejumpers in the Mann Gulch fire disaster. Although not an academic study, it proved to be helpful in understanding how the "disaster at Mann Gulch was produced by the interrelated collapse of sensemaking and structure."[26] It is not hard to envision, given my own personal experience, how and why those men died. Firefighters tasked with wayfinding in smoke are subject to similar loss of sense inside burning buildings.

When historians examine fire and cities, they typically do so to understand how the fire affected the city built environment and research into firefighting practices is often used to support other points. Rarely is firefighting itself the subject of rigorous research. This is left to amateur historians and former firefighters. For example, Mark Tebeau, who describes himself as an "urban public historian and digital humanist" wrote a book titled *Eating Smoke: Fire in Urban America, 1800-1850,* that describes changing firefighting practices within the context of fires in cities.[27] This book was important for orienting the work of this thesis.

Firefighters are in a unique position to make observations about things, especially buildings. Given unfettered access to all types of buildings during (and sometimes before) emergency incidents, firefighters are able to rapidly assemble intimate knowledge about the neighborhoods they serve. Noted Harvard University professor John R. Stilgoe's class and books, *What Is Landscape?* and *Outside Lies Magic: Regaining History and Awareness in Everyday Places* taught me "lessons of visual acuity long absent from grammar school and universities," and how to understand the landscape, or built environment, as a sort of palimpsest where traces of the past can be seen if one looks closely, intently, and sometimes "sideways."[28]

In the same vein as Stilgoe, Shari Tishman's book titled *Slow Looking: The Art and Practice of Learning Through Observation* shaped the direction of this research by emphasizing the importance of visual acuity, as a way of gaining knowledge. Slow looking, according to Tishman, "helps us discern complexities that can't be grasped quickly, and it involves a distinctive set of skills and dispositions that have a different center of gravity than those involved in other modes of learning."[29] There is power in the visual feedback loop she describes – "the more you look the more you see; the more you see, the more engaged you become."[30] As it turns out, there are physiological implications to this as well. She outlines a number of simple methods to improve visual acuity, a few of which can be adopted by firefighters to improve their visual assessment capabilities.

The primary purpose of this thesis is to give firefighters a set of tools to make ever finer and better reasoned distinctions about houses on fire. Developing a discerning eye for houses – the ability to notice details rapidly – and see beyond the superficial styles of houses, is an essential wayfinding skill. Wayfinding in smoke requires that one first understand the "rules," the ordering principles behind house types. Architect and historian Thomas C. Hubka's extensive research on house types, as published in *Houses Without Names: Architectural Nomenclature and the Classification of America's Common Houses,* is the foundation of this thesis. The catalog of houses in Chapter 5 of this thesis is based on his research. It introduces firefighters to two of Hubka's tools: *floor plan analysis* and a *housing census* (i.e., counting houses) and explains how these tools help quantify the houses firefighters fight fires in most often. Hubka shows how "there are only a few basic ways to organize the rooms in houses."[31] A firefighter training curriculum should be constructed around likelihood, where firefighters practice the most-probable skills and spatial configurations first, then the least-probable ones (i.e., they should "train from probability to possibility").[32] Hubka's prototypes, provides firefighters with a training tool they currently do not have – a framework to recognize, name, interpret, and quantify the most-probable combinations of house types for a given area.

Neuroscientist Eric R. Kandel's research into the emotional response to *Impressionist* and *Figural Art* that offers this useful insight for this thesis. In *The Age of Insight: The Quest to Understand the Unconscious in Art, Mind, and Brain*, Kandel explains that "by using the perception of art as an interpretation of sensory experience, we can use existing scientific analysis to describe how the brain perceives and responds."[33] Instead of depicting an object in all its richness, the artists that Kandel studied deconstructed objects, focusing on expressing one or two parts of the whole. Using art as a vehicle, Kandel explains the complicated perceptual and cognitive processes of the brain. His reductive analysis forms the scientific foundation of Chapter 4. He explains that "science seeks to understand complex processes by reducing them to their essential actions and studying the interplay of those actions – and this reductionist approach extends to art as well."[34] This thesis makes an argument to extend this logic to architecture and firefighting.

Neuroscientist Kate Jeffery studies how variegated sensory information is assembled by the brain into more complex, cognitive representations of the world – into "cognitive maps," or spatial mental models, which underly one's sense of place and sense of direction. In "Urban Architecture: A Cognitive Neuroscience Perspective," she outlines how "architectural forms are assimilated and interpret by the brain's spatial-processing system."[35] Her research, and that of other brain scientists has implications for firefighters asked to orient and navigate in smoke – and do so by "feel" and by memory, because the smoke quite often obscures firefighters' vision. Until recent technological developments made it possible to study, wayfinding skill seemed to happen as if by magic. It turns out that there is an "entire brain system devoted to the processing of navigable space," and brain science researchers have shown that "this system underpins memory for life events: so-called episodic memory."[36] Firefighters clearly develop spatial mental models, although no one has studied them *or* firefighters' brains yet. Researchers have, however, studied London taxi drivers' brains and how they come to know the city of London through studying for "The Knowledge," the aptly-named final examination students take before becoming licensed London taxi drivers. Firefighters and taxi drivers share common requirements that they must learn a vast amount of information about the environment in order to navigate to novel locations, "without relying on physical maps or navigation aids."[37]

Firefighters assemble a kind of knowledge about cities (and their built environments) that few outside the firehouse understand or have studied. Firefighters create unique "knowledge spaces," a term used by anthropologist David Turnbull, at the scene of the fire as well as inside the firehouse, around the kitchen table, and on the drill ground. *In Masons, Tricksters, and Cartographers: Comparative Studies in the Sociology of Scientific and Indigenous Knowledge,* Turnbull defines "knowledge space" as an "interactive, contingent assemblage of space and knowledge, sustained and created by social labor."[38] Through experience and sharing stories about their experiences, firefighters develop the ability to perceive otherwise disparate situations, or problems, as similar and then "apply known techniques and solutions. Importantly, they are not verbally defined, but are the product of tacit knowledge which is 'learned by doing science rather than by acquiring rules for doing it.'"[39] Turnbull emphasizes the importance of this kind of "knowledge space" and shows how "much can be learned about the production of scientific and technological knowledge from a consideration of the differing ways in which its heterogeneous components are assembled."[40] This thesis develops a framework for combining the unique experiences of firefighters with existing research from other fields.

Skills, knowledge, history, and culture are shared between generations of firefighters primarily through oral traditions. Very little firefighting "know-how" is written down. Rather, firefighting "know-how" is performed, dramatized, and made into something portable *and* memorable in part through *story*. These stories can be evocative, filled with descriptive imagery, engaging, and effective tools for instruction, if one knows what to listen for. Kendall Haven's book *Storyproof: The Science Behind the Startling Power of Story*, defines a story as something with a specific narrative structure. Stories, according to Haven, are powerful and effective because it is "easier for the mind to extract and understand" essential information from something structured as a story.[41] The *who*, *what*, *where, why, when,* and *how* of firefighting is often contained within these stories. Of special significance to firefighters, however, is *where* the fire took place. In *Wisdom Sits in Places: Landscape and Language Among the Western Apache*, anthropologist Keith Basso describes Western Apache language and landscape naming practices. His research proved helpful to understand the power of "spatially anchored" stories.[42] In his book, Basso explains the importance of the "descriptive specificity" in Western Apache place-names and likens them to vivid "pictures."[43] According to Basso, "place-names are used in all forms of Apache storytelling as situating devices, as conventionalized verbal instruments for locating narrated events at and in the physical settings where the events occurred."[44] Firefighters and the Western Apache people (among other indigenous cultures with storytelling practices) share similar oral traditions, but firefighters lack specific terminology to describe the environment, or the places, they operate in. They do not situate their experience and "know-how" well. The tradition of "learning the names" of places allows the Apache people to "construe their land and render it intelligible."[45] Thus, Western Apache practices might offer contemporary firefighters a guide, or "map," to put names to the places where they gain their wayfinding experience — to make this environment intelligible and communicable to future generations.

This thesis investigates how firefighters come to know the inside of houses they fight fires in. Although not a scientific study of perception and cognition, the thesis brings together aspects of the complicated processes behind firefighters' ability to wayfind in smoke as recounted in stories told by firefighters, as described in the "Wayfinding in Smoke" survey responses, as well as from the author's personal experience as a firefighter. It assembles these accounts into something understandable and useful to firefighters (and maybe others). It proposes a simple tool, the catalog of houses, in an effort to improve existing firefighting practices. By leaning heavily on sources "outside" those typically cited within the American fire service, this thesis presents useful research within the context of firefighting practice. This thesis takes an inter-disciplinary approach. Referring to the nuances of different knowledge systems, Turnbull points out, "though knowledge systems may differ in their epistemologies, methodologies, logics, cognitive structures, or in their socio-economic contexts, a characteristic that they all share is their localness. However, knowledge is not simply local, it is located. It is both situated and situating."[46] This thesis examines the place where firefighting knowledge is assembled and used, where seemingly unrelated disciplines share common ground – inside a burning house.

Thesis Structure

This thesis is divided into six chapters with an associated literature review and bibliography. *Chapter 1: Firefighting Equipment, Practice, and Standards,* introduces the reader to relevant concepts in firefighting practice, including a summary of the basic firefighting units, the development of wayfinding practices by firefighters, and the protective equipment firefighters wear. *Chapter 2: Training Firefighters,* outlines the specific phases of firefighting training in order to illustrate how firefighters are taught to find their way in toxic smoke. *Chapter 3: Wayfinding In Smoke* summarizes important theoretical concepts and principles of human spatial orientation and navigation. It places specific emphasis on the historical, cultural, and practical realities of finding one's way in an environment that can kill residents and/or firefighters. *Chapter 4: Understanding What Firefighters "Know,"* explains how the nervous system, of which the brain is a critical part, is creative in how it gathers, stores, and uses information. Successful wayfinding inside a building on fire is intimately linked to a firefighter's ability to recognize different interior configurations and quickly orient spatial mental models to present conditions exploiting the brain's capacity for "model-building" and hypothesis testing.[47] *Chapter 5: A Catalog of Floor Plan Types,* examines how a typology of historic and contemporary floor plans, regular geometric patterns, and established phenomenology in the residential built environment may be useful as a navigational tool to help firefighters *make sense* when they are tasked with navigating toxic smoke to search for trapped victims and to locate the seat of fire. In this chapter, the reader is oriented to the development of residential floor plans and their power as a mnemonic tool to help firefighters orient and maintain orientation as they navigate. In *Chapter 6: The Catalog as a Tool of Thought, Memory, and Action,* cognitive tools such as stories and visual representations have proven to be especially powerful navigational and sensemaking tools. Stories and visual representations are externalized memory aids and parallel how the brain processes information. *Chapter 6* discusses using the typology of historic and contemporary floor plans as a guide with further explanation of how they fit into firefighting culture and training. These chapters are followed by a *Conclusion* that discusses the applicability of the thesis to current firefighting practice, the potential to expand the catalog beyond residential building types, and the broader potential for studying the cognitive and physiological basis for firefighting practice, particularly in devising effective training curricula for firefighters.

Personal Reflection

Although some authors and a few scholars have addressed the changes in building construction in response to fire, comparatively less scholarship exists documenting how physical changes in the built environment drove changes in firefighting technology, fire suppression techniques, and wayfinding in smoke practices by firefighters. Almost no scholarship exists on how firefighting training and practices evolved to confront the developing fire problem in growing cities. Much of the information that is available is found primarily in fire department archives in the form of training records; in stories firefighters tell about their experience; or in oral accounts and news reports and coverage that follow big fires. Fires in single-family houses rarely receive news coverage commensurate to fires in other occupancy types – theaters, schools, apartment buildings, and commercial occupancies, and so forth. The development of firefighting practice, specifically wayfinding in smoke in urban American single-family houses, is a compelling untold story, as record of its evolution exists in few places outside the firehouse. Yet as Mark Tebeau explains,

> "Firefighters remade the labor and the mission of urban fire departments when they fought fires more aggressively and faced an increasing amount of hazard as they penetrated deep inside the shakily built urban infrastructure. Firefighters also discovered a framework and rationale for their occupation as they began to rescue more and more people trapped by flames."[48]

The house is a site of memory, it collects experiences and acts as a retrieval cue for human memory processes – even more so when it burns. Marc Treib writes, "thus, we might say that there are both memories in and memories (projected) upon our built environment – they become repositories into which, and from which – like a bank – both deposits and withdrawals may be transacted: the built environment as a memory bank, both individual and communal."[49] Firefighters, in a sense, are preservationists. We make it our professional business to protect *people and places* from fire. Firefighters work to preserve the lives and memories sheltered within their walls, and in the process, we create our own memories. Thus, if the house is the site of memory for a family, it becomes the site of a second set of memories when it burns – those of firefighters who often experience this environment under the most difficult of circumstances. Their experiences offer a rich set of memories that have remained largely unrecognized and untapped as a resource for research.

Any serious inquirer into the wayfinding practices of firefighters must carefully scrutinize the environment this work is performed in. They must "look sideways" and ask the question – what am I *not* seeing that I *should* be seeing?[50] Stilgoe recommends: "pay attention to what you are not supposed to notice."[51] It benefits from work by scholars in brain science, psychology, and architecture, but it also pursues a body of knowledge and experience that has flourished outside traditional academic scrutiny and influence. The experience of firefighting and the stories of firefighters that make up this body of hidden knowledge is the beginning point for this thesis. It starts in the next chapter by examining major influences that pushed firefighters deeper into burning buildings – deeper into the smoke.

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CHAPTER ONE

Firefighting Equipment, Practice, and Standards

"The fire is the enemy; but he can fight that, once he reaches it with something of a chance. The smoke kills without giving him a show to fight back. Long practice toughens him against it, until he learns the trick of 'eating the smoke.'"[1]

– Jacob Riis

1.1 Introduction

Addressing the problem of fire is a uniquely human endeavor. At many points in history, the citizenry as a whole, was enlisted to help fight fires in cities. Before professional fire departments, citizens often battled fires up close, with buckets of water and long hooks – from the outside. Responding to fire was once a common human experience. This is no longer the case. Knowledge about fire and firefighting is now concentrated among specially trained firefighters who have chosen this profession and devote their careers to extinguishing fire and saving lives. Few others ever experience the heat and sensory overload that comes from a building on fire.

Today, only a few people understand or have experience with the gritty reality of fighting fires. The problem of fire is integral to the history of the urban built environment. In *Eating Smoke: Fire in Urban America, 1800-1850*, history professor Mark Tebeau writes that "no other environmental danger jeopardized the entirety of the city-building process — encompassing human life, property, and the dreams of city boosters — in such a sweeping or intense fashion."[2] Population growth in cities stretched firefighting capabilities to their limits and industrialization compounded the American urban fire problem in the nineteenth and early twentieth centuries. As urbanization and building construction outpaced the technologies of fire protection, large portions of most major cities burned. Former firefighter Bruce Hensler, in *Crucible of Fire: Nineteenth-Century Urban Fires and the Making of the Modern Fire Service,* writes:

> The fires and conflagrations provided a crucible of learning for firefighters, builders, architects, engineers, insurance underwriters, developers, and civic leaders. From these times grew new methods of building construction, new building materials, high-capacity water systems, building codes, and a body of knowledge in fire protection.[3]

Despite their deadly record, urban fires have always served as a harsh means of education and a catalyst for change and civic improvement.

1.2 Historical Context

Study of the historical firefighting record and debate on the merits of experience in this environment have taken place primarily inside the walls of firehouses, specifically at the kitchen table, often over a meal. In places like Seattle, it happens in the "beanery" — the historical name for the kitchen, first used by the new professional firefighting corps after Seattle's Great Fire in 1889. It is here that one may begin to understand how firefighters meet these new challenges. Late scholar of firefighting, Miriam Lee Kaprow wrote in "The Last, Best Work: Firefighters in the Fire Department of New York:"

> The meal in the firehouse incarnates and dramatizes a symbolic or cultural universe that is an alternate to the world of civilians outside the firehouse. For the firefighters, the essence of this alternate world is the fire site. In this alternate world, time slows down, then stops, total concentration blots everything out, and experience becomes transcendent. These elite (for they think of themselves as elite), these happy few who eat together in a place where no one else may eat, are the same persons who enter a place no one else may enter. They engage in the mythic and solemn task.[4]

The corps of professional firefighters may, in some ways, seem the modern equivalent of a thriving secret society, one with its own exclusive social structure and hierarchy, initiations, rites and rituals, specially designed meeting locations (the firehouse), myths, and rich culture including customs, tradition, ethos, dress, and ceremony — especially in death. Kaprow writes,

> In addition to its exclusive social structure and rituals, the firehouse has a powerful occupational culture that separates its members from outsiders. This culture is organized around the idea of 'heroism' – the voluntary commitment to personal sacrifice in the face of patent physical danger. Elaborated in charter myths, in oral and in written history, this occupational culture is steeped in beliefs about firefighting as an elite and sacred enterprise. Firefighters, I should add, meticulously avoid using the word 'hero,' but their own descriptions of their work replicate much of the content of medieval heroic epics.[5]

Eating together, in this communal ritual, "seals the covenant."[6] It solidifies two important tenets of the firefighting ethos: "first, to do battle with fire, an engulfing environment that destroys life; and second, in the midst of this struggle, to cheat death by giving life, by rescuing people."[7] Firefighters spend significant time in both ordinary *and* extraordinary situations. But the culture surrounding the firefighter's sharing of stories at the dinner table helps to explain why little is known about the commitments and challenges of firefighting outside these tight circles.

What is missing from the historical record, even if firefighters recount them around the table, are detailed accounts of how firefighters learned to find their way in smoke. The absence of such accounts may be partially attributed to the deliberate reluctance of members to speak about the firefighting rituals to outsiders. Only those members of this community come to know the intimate details of that experience. Similar to historical craft guilds, one may say that firefighters fiercely guard their "secrets" and are selective about sharing. "Initiation" for new firefighters involves a long period of training, during which recruit firefighters learn the craft and are often taught skills inside burning buildings under direct supervision of senior firefighters. The story of how firefighters have learned to fight fire and "eat smoke" takes one into dark, smoky hallways and rooms, and ultimately face-to-face with fire and the threat of getting lost.

1.3 Firefighting Practice, A Brief Overview

In the early days of firefighting, volunteer firefighting corps (and ordinary citizens asked to help) were no match for the speed at which fire spread. Cities constructed of wood burned easily. Before 1900 cities usually lacked the firefighting infrastructure to supply the volume of water required to suppress fires quickly, and as a result, small fires often rapidly expanded to become large conflagrations. Firefighters who responded to these immense conflagrations were often faced with insufficient water supply, inconsistent water delivery, and inadequate equipment. Their tactics were reactive, and their efforts were directed primarily from the building exterior (see Image 1.1). As a result, many late nineteenth century building codes accepted that fires would occur in urban environments, but adopted a strategy of compartmentalization to limit the spread of fires beyond the buildings in which they began.[8]

The earliest evidence of firefighting practice dates as far back as ancient Egypt. Those efforts depended primarily on bucket brigades; a technique refined in Nero's Rome.[9] Later, simple pumps supported the effort. Author and historian Torbjörn Lundmark, a freelance author on occupational health and safety, writes,

> If fire was the source of danger, water was the solution; the Pharaoh's Fire Brigade got it from the Nile, the Roman *vigiles* from the Tiber (the Romans also invented the concept

Image 1.1 Exterior firefighting as illustrated in this etching by Jan van der Heyden from December 5, 1658.[52]

of 'passing the bucket'). The *pompiers* of Paris siphoned the Seine, and London's 'smoke-eaters' pumped their water from the Thames.[10]

Before the 1860s, firefighters in the United States relied on hand-powered pumping apparatus using technology invented by Richard Newsham in 1725.[11] Steam engines, introduced in 1841, improved water delivery and produced more consistent water pressures, but even these machines could not deliver the volume of water needed to extinguish large fires. Improved fire hoses, combined with improved pump technology, significantly changed how firefighters attacked fires in the late nineteenth and early twentieth centuries. Improvements to hose design, material composition, and construction allowed more water to be pumped from farther away and directly *into* buildings on fire. Improvements in hose and nozzle technology built upon innovations by Jan van der Heyden in the seventeenth century. Van der Heyden (and his brother Nicolaas), patented a new water delivery device to combat fires. The device, called "a 'snakepump' (*slangpomp*)," was designed "to pump water under constant pressure through long hoses directed toward or carried into burning buildings."[12] It was a specific application of the device that cemented his place in firefighting history. His "flexible, snakelike hoses, made of leather and sewn with linen or hemp thread" proved to be "the most innovative and influential feature of

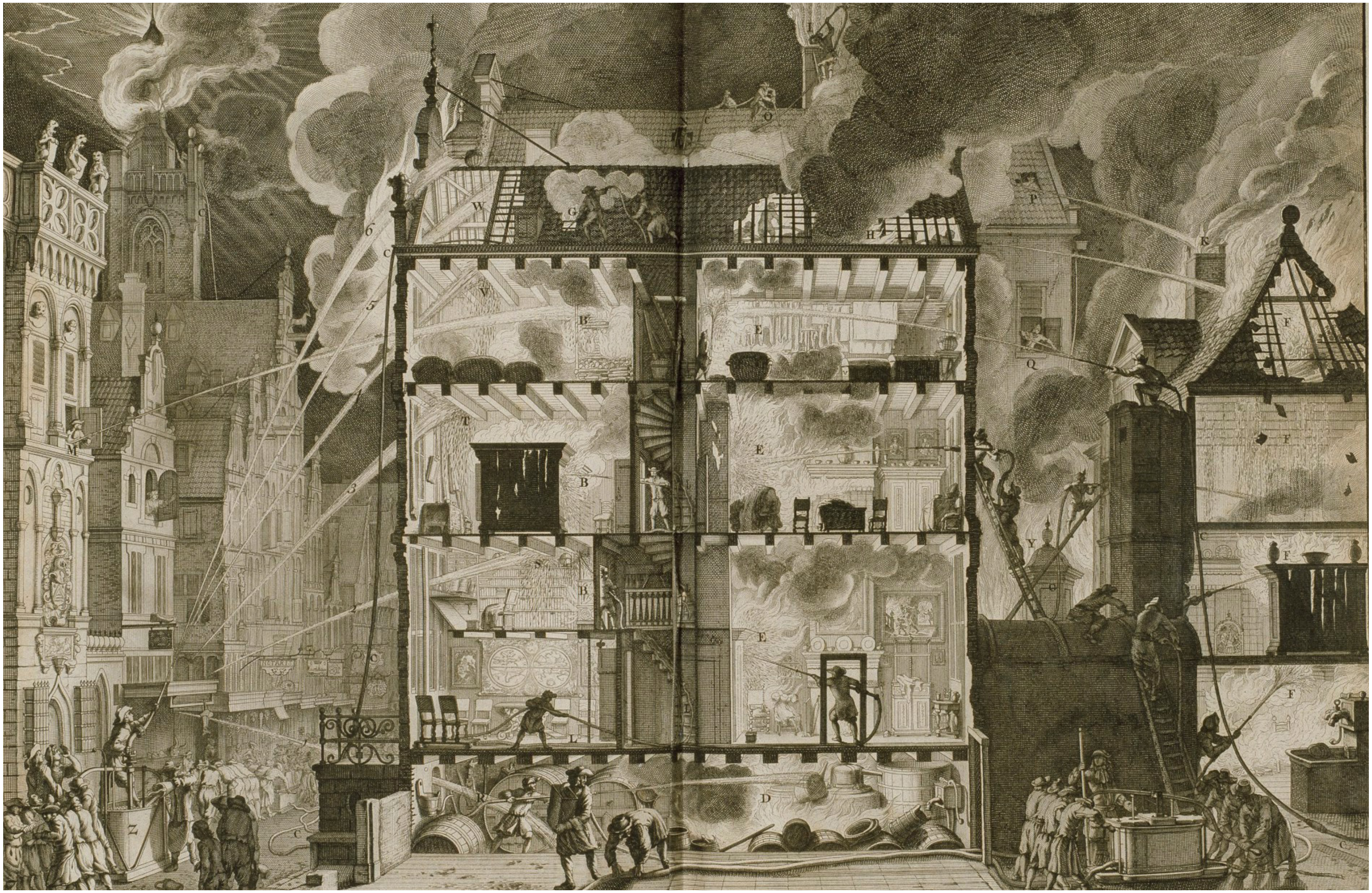

Image 1.2 Interior firefighting as proposed by Amsterdam Fire Chief Jan van der Heyden in the seventeenth century.[53]

his new system."[13] Art historian Susan Donahue Kuretsky, in "Jan van der Heyden and the Origins of Modern Firefighting," explains that Van der Heyden's "system" refers to the method of fire suppression where pumps and flexible hoses allow firefighters to fight fires from *within* burning buildings. The contrast, between what Van der Heyden proposed and what was then current practice, is evident in the stunning etching he created to depict the advantages of combating fire from *within* buildings (see Image 1.2). Kuretsky writes,

> As a technical illustration, this print, etched and engraved from careful preparatory drawings and lettered to draw attention to points of interest, immediately convinces the viewer that a new world of firefighting has arrived. From all sides, powerful jets of water, pumped from the ground, are directed upward into the flaming houses, as firemen with long hoses swarm onto ladders and rooftops. Within the central structure, they clamber up narrow stairways and rush into rooms at all levels, even the attic and the basement, where the fire may have begun in the storage containers at the right.[14]

Kuretsky continues,

> The disciplined, tightly organized procedures in fighting fire with new equipment may not save the owners' possessions, but the containing walls of the affected buildings will clearly survive with nearby structures spared. The importance of immediately addressing a fire from within a building, which Van der Heyden's new hoses made possible, was and remains of paramount importance in such rapid-developing situations.[15]

Van der Heyden's fire hose and emphasis on interior firefighting plays a significant role in fire suppression theory and practice still applied today. Delivering water quickly and consistently to the seat of fire is essential to stop combustion, slow the production of toxic smoke, preserve property, and save lives. Van der Heyden's etching evokes the

> Wonder and terror of events in which the largest creations of human effort and ingenuity are seen to be under attack by an assailant who arrives unexpectedly, whose strategy is unpredictable, and who can rarely be vanquished before severe damage or injury has been inflicted.[16]

He captures "the incessant movement and high drama of a battle in progress as battalions of small, active figures methodically infiltrate the scene" to extinguish the fire.[17] Van der Heyden's etchings allow the viewer to see through the smoke that undoubtedly fills the burning house and examine firefighters' actions. Few, aside from firefighters, will ever actually experience what goes on inside rooms made ink black by toxic smoke.

Van der Heyden understood before many that the most effective fire suppression takes place inside the burning building – from hallways and inside compartments (meaning rooms), with water aimed directly at what is burning. Interior fire attack is a modern development in firefighting practice made possible by the creation of city water supplies, durable fire hose, consistent pressure delivered by pumping apparatus, nozzles that produced an effective stream, and personal protective equipment (PPE). All of these advances allowed firefighters to push deeper inside buildings to extinguish fires at the point of origin. Interior fire attack also performs another, equally critical function – firefighters stretch their hose lines to take up positions inside to try to protect those who are trapped in the building from fire. Thus, firefighters apply water to accomplish three objectives, as articulated by Seattle firefighter Aaron Fields of the Nozzle Forward (a firefighter training initiative) – first, to "*take*" space back from the fire; second, to "*make*" survivable space inside; and third, to exert "*control*" on the interior environment.[18]

The nozzle firefighter, takes space back from the fire by directing the stream of water toward the fire, using the reach of the stream, and aiming it out ahead and toward the highest temperature gases (usually at ceiling level). By this action the firefighter can remove heat energy from the environment. To *take* space back from the fire means that the firefighter applies water (referred to by firefighters as "coating" the surfaces) to all six sides of a compartment, starting with the most-dangerous ones first (those at the ceiling). Applying water in this hierarchical order cools the burning surfaces and stops or greatly slows combustion.

This cooling action produced by coating the surfaces makes a survivable space by slowing the production of toxic gases and allowing lower temperature gases to rise. When water hits the surfaces at the top of the compartment, the superheated gases trapped there (which take up a large amount of space at the top of a compartment) rapidly cool and, as a result, contract. The rapid cooling and contraction of superheated gases at the ceiling has the effect of drawing cooler, cleaner air into the compartment (room or hallway) at the floor. Those victims of the fire who may have been incapacitated due to breathing hot gases and toxic smoke, now have cleaner air introduced into their general area.

The nozzle firefighter exerts control over the environment by continuously moving the nozzle to create a high-pressure front of water and air that effectively seals the burning hallway or compartment from spaces behind the nozzle firefighter. By continuously moving the stream of water in an inverted-U and O-pattern, the firefighter creates a higher pressure in the compartment ahead. This effectively forces the products of combustion to reverse direction, moving away from the nozzle firefighter. If the nozzle firefighter were to hold the nozzle stationary, the superheated gases could move right around the stream of water. The nozzle firefighter physically separates what is burning from what is not by the use of water and the air it entrains. And the nozzle firefighter seeks to reduce the volume of superheated toxic gasses to draw cooler more breathable air into the floor area where people may be found incapacitated.

Firefighters regularly employ two methods of confinement – the *push*, and the *hit and move*.[19] In fires that have advanced beyond the room or rooms of origin, the *push* is used. To *push* means to continuously flow water *and* advance toward the fire. The team of firefighters opens the line and leaves it on as they move the hose into the fire room. (Note, however, that not all fires require a firefighter to flow water while advancing on the fire. Smaller, incipient stage fires do not require this technique.) In situations where the firefighter cannot reach the burning material directly, the *hit and move* confinement is used. To use a *hit and move* method of confinement, the team of firefighters opens the line to cool the environment out ahead, shuts down, moves into position, and flows water again when their stream of water can reach what is burning.

The *push* was a method developed and used by (pre) self-contained breathing apparatus (SCBA) firefighters.[20] Essentially, the *push* was required before the introduction of SCBA to ensure firefighters could breathe. By flowing water while the nozzle team advances on the fire, when appropriate, firefighters could create a cooler environment and by this action they create space that has been proven to save lives, including their own. The push is generally performed five to twenty-five (5-25) feet from the main body of fire and has been recently scientifically validated by the Underwriter's Laboratory (U.L.) in multiple fireground experiments.[21] Modern scientific tools have empirically validated what firefighters once understand only from experience – that in order to survive, firefighters need to flow water to: stop combustion, to cool the environment, to stop the production of smoke, and to breathe.

1.4 "Eating Smoke"

These techniques, while effective in controlling fire, are often not adequate to protect firefighters and the victims of fire from smoke. Smoke obscures the environment in ways that have profound effects on visibility, the speed of movement through a space, and on survivability – for both the civilian and the firefighter.

Conditions are not uniform throughout a building on fire, but the amount of heat energy and the density of smoke does change in a somewhat regular manner depending on one's position and the location of the fire's point of origin, or its seat. The quality of the fire environment follows a simple metric – visibility in this environment is worse near the seat of fire and generally better farther away from it; the same goes for heat energy. Smoke moves geometrically throughout the structure – following the path of least resistance as it fills the space. The physics of fluids dictates that smoke moves from areas of high-pressure to areas of low-pressure.

A fire produces smoke as a result of incomplete combustion. Smoke is composed of a myriad of super-heated, toxic chemicals, vapors, fumes, oils, and particulate matter. Some toxic components of smoke are created by the combustion of different materials and the way gases mix in this environment. Asphyxiant gases such as carbon monoxide (CO), hydrogen cyanide (HCN), and carbon dioxide (CO_2) cause "incapacitation through effects on the central nervous and cardiovascular systems. Most asphyxiant gases produce their effects by causing brain tissue hypoxia i.e. reducing the amount of oxygen delivered to the brain."[22] The presence of irritant products of combustion (generally, particulates) in smoke results in "sensory irritation, which causes painful effects to the eyes and upper respiratory tract and to some extent the lungs."[23] Visibility and survivability are dictated by the extent of fire, the ventilation profile, the configuration of rooms, one's position within the environment, and one's length of exposure to this toxic soup. Smoke undoubtedly makes navigating more difficult, movement slower, and imposes greater cognitive demands on the firefighter. Smoke kills before the fire does.

The history of developments in firefighting practice is paralleled by the history of developments in respiratory protection. Lundmark writes,

> "Not only scientists, doctors and professors but also amateurs, tinkers, dabblers and enthusiasts worked on countless innovations. Even coal miners whose lungs blackened underground wanted clean air to breathe and tried their hands at various contraptions. It is difficult to establish one person who was the first to invent a workable breathing apparatus, and there are many famous names in the history of supplied air. Some of the early inventors include the diving specialist Sir Robert Henry Davis, the fire officer Sir Eyre Massey 'The Skipper' Shaw, the Irish physicist Professor John Tyndall, the Italian scientist Giovanni Aldini, and the miner and amateur inventor John Roberts. The French were at it too: the *Sapeurs-Pompiers* of Paris came up with the so-called *Appareil Pauline*, an upper-body covering, into which air was pumped with a bellows outside the building. In England, the device was known as the Smoke Jacket and was made of cow hide."[24]

One need not look far for heroic stories of people – civilians and firefighters alike – putting their life up as collateral to rescue those trapped by the smoke and fire – *without respiratory protection*. It should be noted that people of all eras of human history have recognized the need for respiratory protection long before firefighters, but respiratory protection within the American fire service came of age in the nineteenth century.

Beginning in the mid-1800s, as a practical solution to the threat of toxic smoke, firefighters tested many seemingly strange and unusual inventions to prevent them from having to breathe smoke.

Low-tech solutions like breath-holding proved popular with firefighters, but this technique only allowed the firefighter to travel a short distance inside a building. "Firemen would run through smoke-filled rooms, grab an unconscious person, drag him out, and start breathing only after that."[25] Firefighters developed a variation to this called *skip breathing* as a way to travel deeper into the smoke. The firefighter would quickly search the room, open a window to "grab a blow" of fresh air and skip breathing until they made it to the next room. Firefighters would also "spell" each other on the hose line. This required staying low, hunkered down at the floor while the nozzle was open and water was flowing through it. Because the stream of water draws fresh air in behind it, at the nozzle is usually where the cleanest air is in the smoky room. When the firefighter could no longer take breathing smoke-filled air, they would take a "spell" in the hallway and another firefighter would take over at the nozzle. Kaprow writes of a firefighter who said, "we still say 'you go out to take a blow,' which means you go out to get some fresh air. And one reason they taught you to stay calm as a young fireman, was that if you got excited, you'd breathe heavily and suck in more toxic gases."[26] In other cases, firefighters reported using pieces of wet clothing, or trying crude filter masks. Notable are the stories of firefighters clenching wet moustaches between their teeth to filter the smoke.[27] In fact, this is one of the reasons firefighters before SCBA had long, handlebar moustaches. The moustache was likely the "first filter mask in the fire service. They used to breathe through their nose with the moustache screening out airborne particles of smoke and toxic dust."[28] (Many historical photographs of firefighters show the commonality of the moustache.) Some reports during the eighteenth and nineteenth centuries, state that "firefighters were required to have full grown beards."[29] This requirement stands in contrast to the requirement today that firefighters be clean-shaven where the respirator seals against the face. Firefighting, in general, was painful and often deadly before the use of positive-pressure respirators that are now standard industry-wide. According to the U.S. Navy's chief respirator expert David Spelce, et al., who writes in "Pre-World War I Firefighter Respirators and the U.S. Bureau of Mines Involvement in WWI," that at the beginning of the industrial revolution,

> Respirator evolution became more sophisticated. In 1825, John Roberts developed a 'smoke filter' for firefighters, consisting of a leather hood and a hose strapped to the leg. The design was based on the correct assumption that the most breathable air during a fire was near the floor. An inverted funnel at the end of the hose contained a woolen cloth to trap particulates and a wet sponge to protect against gases and vapors.[30]

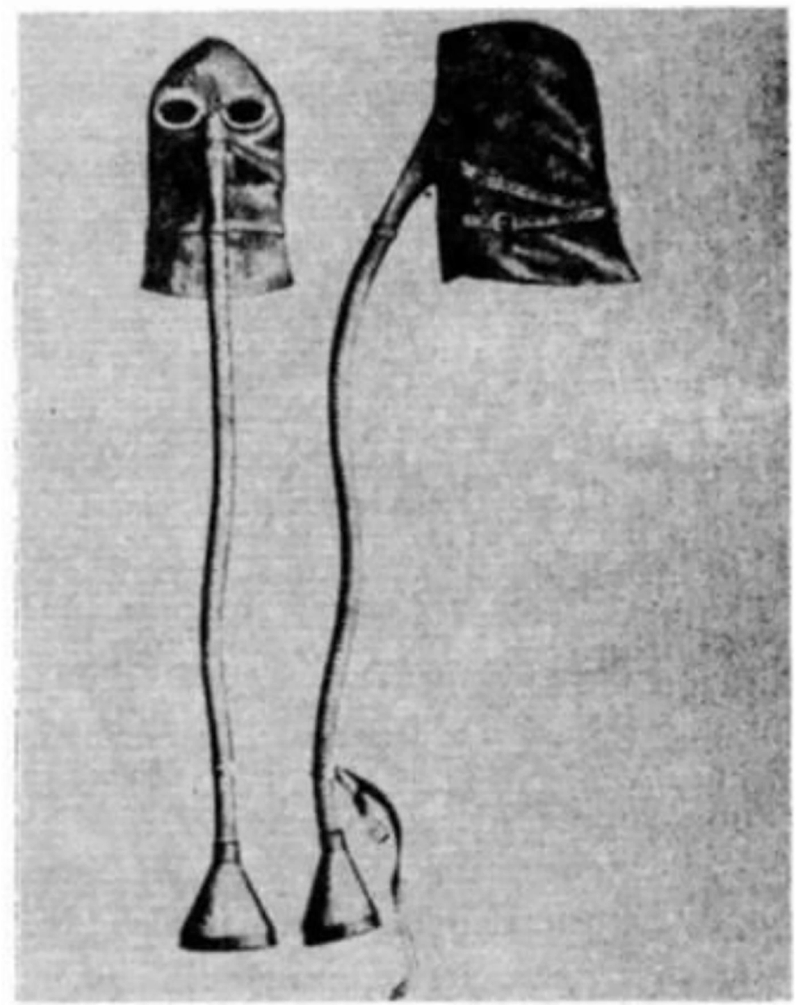

Image 1.3 John Roberts' 1825 "Smoke Filter," which included an "inverted funnel at the end of the hose" containing a "woolen cloth to trap particulates and a wet sponge to protect against gases and vapors."[54]

As reported by Kaprow in "The Last, Best Work":

> The real reason you couldn't go into smoke and a burning room without a mask was that your eyes would burn. Smoke is actually solid particles finely divided – solid particles of carbon that full up your eyes. One of the big injuries years ago was conjunctivitis. Firemen would have red, swollen eyes for two or three days after spending an hour in or around a burning building. Also, you could not inhale that smoke. You'd start to gag and cough and sometimes vomit, especially if you'd had a big dinner before. I remember vomiting in a fire. The gag reflex was what really prevented firemen from going very far in.[31]

In the same paper, Kaprow also wrote:

> For firefighters, being able to breathe while fighting a fire and while searching for victims (or each other) is a major preoccupation, especially before the development of good masks. Air also has been the focus of manly games and status: the challenge of "leather lungs" – of seeing which firefighter can survive the longest without it.[32]

The ubiquity of fire department initiation rituals that involved breathing in smoke is another indication of the recognition of the problem – it was something firefighters simply had to learn to face. In the Seattle Fire Department, this rite of passage was literally called "smoke school." The point was to indoctrinate new recruits to "eating smoke," and later to see who could breathe smoke the longest. Kaprow, describing a common experience (not just in Seattle), writes,

> They used to play a game in the firehouses, the leather lungs game. They'd fill up a garbage can with wood and cloth, and

Image 1.4 Engine 69, "Harlem Hilton," Fire Department of New York (FDNY) making entry into the smoke. Michael Dick photo.[55]

> light a fire in it, and let the room fill up with smoke. Then they'd send the firemen in, young and old, and see who could stay in the room longest. One by one the firemen had to leave the room to get some fresh air. The guy who stayed in the room longest was looked up to: he had won the game.[33]

Until relatively recently, firefighters faced life-threatening toxic smoke with no good way to protect themselves, particularly their respiratory tracts. As recently as the 1980s, there were few practical solutions to address the threat of breathing toxic smoke. It took many years before self-contained breathing air (SCBA) technology was available to firefighters and could be put into practical, everyday use. Even after the technology was serviceable, many firefighters refused to use it. This new technology was not accepted uniformly – and it still meets resistance in pockets of firefighting cultures throughout the United States. To "eat smoke" or "take a feed" as firefighters call it, was (and still is) considered a "badge of honor." To have "leather lungs" was the ultimate compliment, and the time spent earning those lungs was a rite of passage into this exclusive society.[34]

In addition to these pockets of cultural prejudice against SCBA, there are several practical reasons to use it with caution. Modern protective equipment has insulated the firefighter from instant feedback from the environment. This technology allows firefighters to advance deeper faster than ever before, and they may fail to recognize crucial environmental cues (for example, fire and smoke behavior, heat energy, landmarks, and one's position within the environment). Nevertheless, SCBA has become essential equipment for firefighters because one's ability to survive inside the fire environment is entirely influenced by the amount of fresh air available. Today, compressed air is carried inside the SCBA tanks firefighters are required to wear. Firefighters carry a limited supply of fresh air in their SCBA — a cylinder rated for 30, 45, 60 minutes of normal breathing may only supply air for 15, 20, or 30 minutes (or less), with exertion. The drawdown rate of air stored within the SCBA is related to one's state of arousal, physical conditioning, assigned physical task (i.e., advancing a hoseline, searching), and air consumption rate. Additionally, as a still-improving technology, SCBA can and has failed leaving firefighters without fresh air to breathe inside a burning building. Of concern to this thesis are the physiological effects on wayfinding related to the introduction and use of personal protective equipment (PPE) and SCBA. Firefighters are tasked with wayfinding in smoke but do so under the weight of heavy PPE. While heavy and cumbersome, PPE (including SCBA) is necessary for the health, safety, and successful completion of fireground tasks.

As standard practice, firefighters wear two layers of PPE inside a fire: the *station uniform* and the *structural firefighting ensemble*. The station uniform consists of heat and flame-resistant Nomex pants and shirt. The structural firefighting ensemble consists of a helmet, boots, thermal protective clothing (coat, pants, hood, gloves), and SCBA (which includes the air cylinder, its backpack frame with shoulder straps, and facepiece with regulator). The PPE weights approximately 55lb (22.1kg in total) and increases physiological demands, fatigue, limits mobility, significantly reduces perceptual ability. The bulkiness of the PPE has been shown by numerous researchers to increase blood pressure, heart rate, and the risk of cardiovascular disease. Additional tools (for example, flashlights, halligan tool, New York hook, pike pole, water can, and thermal imaging camera (TIC) all increase a firefighter's weight. Ladders, fire hose, saws, and other tools increase one's weight further beyond the equipment listed above. Today, it is not uncommon for the firefighter to carry an additional load close to 100 lbs. (including PPE) *beyond* their own body weight. Any examination into firefighting practice should begin with an understanding of the PPE firefighters are required to wear.

Figure 1.5 Modern personal protective equipment (PPE). Jordan C. Legan photo and illustration.

During fire suppression and search tasks, physical demands vary greatly based on the task being performed. Today, firefighters are *required* to wear SCBA when performing interior suppression and search/rescue operations. In general, firefighting consists of varying periods of high-intensity anaerobic *and* aerobic tasks. In a journal article titled "Implications of Aerobic Fitness on Firefighters' Occupational Performance, Health, and Risk of Injury," researcher Emily Langford et al. writes that,

> The use of PPE, along with self-contained breathing apparatus (SCBA), encapsulates the body, preventing normal heat distribution. The PPE increases the aerobic demands of a given task due to the additional load (20kg or more, depending on equipment). In addition, the combination of the positive pressure design of the SCBA regulator and the SCBA harness, which restricts the firefighter's ability to expand the chest cavity, increases the energy expenditure required to expel carbon dioxide, and produces decrements in aerobic capacity by 8-22%. Moreover, this protective ensemble increases heart rate by 20-30 beats per minute (bpm) and systolic blood pressure by 15-23 mmHg. From an occupational performance perspective, Lesniak and colleagues recently reported that SCBA use plus PPE yielded a relative increase of 44% in time to complete simulated fireground tasks compared to wearing physical training clothes only. Therefore, the effects of PPE and SCBA must be accounted for when discussing the strain associated with firefighting.[35]

The public, their colleagues, and their own lives depend on firefighters' ability to rapidly complete fireground tasks and wayfind while wearing heavy, cumbersome PPE. As Kaprow writes, "in firefighting, dangers are not restricted to injuries caused by flames, collapsing buildings, or falls. A major source of danger is air – either the lack of clean air to breathe or the effect moving air has on fire."[36] Firefighters become intimately familiar with importance of air in this environment because they need it to live and can die by it.

While SCBA reduces the danger of breathing toxic smoke by supplying fresh air for breathing, and protective equipment provides a degree of safety, firefighting can still be deadly. The combination of smoke and fireground noise can be disorienting and sometimes lethal. The heavy protective clothing (referred to as "bunker gear" by firefighters) that today completely encloses firefighters' bodies, amplifies disorientation by limiting vision, hearing, and the experience of temperature. For example, firefighters commonly report being able to use their ears, or the back of their hand to tell the temperature immediately around them, contemporary personal protective equipment (PPE) has all but eliminated the ability to make an accurate assessment of temperature. These factors along with sporadic radio communication reduce firefighters' sensory acuity while also shifting their attention in multiple competing directions. In interviews with older firefighters who had learned to pay close attention to environmental cues such as their body position, heat level, smoke (color, taste, and direction), and sound reported finding that the introduction of SCBA and new protective bunker gear isolated them from much of the information they had previously used to make sense of the environment in a fire. Firefighters consistently work from their knees in a head-down/up orientation and must have good body awareness in an environment where landmarks are made invisible and vision is distorted by the smoke. This is made difficult by the protective ensemble. For example: firefighters use feel to identify furniture, rooms, and sometimes people through bulky gloves. Their hood and the noise of breathing through the positive pressure, demand regulator of the SCBA limit one's ability to hear well. Heat energy can be felt through the protective ensemble which may help orient one to the location of the fire, but it also increases firefighters' core temperature. While the ensemble isolates firefighters from the toxic environment of a fire, all of the equipment adds weight. The weight of the PPE, SCBA, hoses, and firefighting tools present challenges to movement and even physically fit firefighters tire rapidly adding yet another layer of complexity and danger. Firefighters operate at the very limits of their physiological, perceptual, and cognitive abilities on a regular basis.

Firefighting practice then, should be understood through two principal tasks – *search/rescue and fire suppression* – under time pressure in acutely-stressful, volatile, uncertain, complex, and ambiguous fireground situations.[37] There are three functional units of firefighting who work together to address the principal tasks as quick as possible. This thesis addresses an area that has received little scholarly attention – how firefighters (individually and collectively) wayfind inside houses to rescue those trapped or incapacitated by smoke and fire. Modern technology allows firefighters to move deeper into toxic smoke oblivious to the temperature and conditions around them. Of specific concern to this thesis is how knowledge and data gained from this experience is encoded, consolidated, stored, and retrieved – individually and collectively as a group.

1.5 The Functional Units of Firefighting

In general, fire departments are functionally organized into three distinct groups – *Engine Company*, *Ladder Company*, and *Incident Command*. Each fire company, or functional unit, has its own area of responsibility: fire *suppression*; *search and rescue; and command/supervision, respectively*. In this regard, each fire company is a type of ecosystem situated within the larger fire department system. As a dynamic ecosystem, fire companies are a team composed of individuals with varying skill/training/expertise (from novice to expert), perceptual and cognitive demand (based on assigned position), responses to stress (on a continuum).

These fire companies (engine and ladder companies, specifically) form a modular system of fire suppression and emergency medical response, collectively supervised by chief officers that can be scaled up (expanded) to meet the fire problem. It should be noted that fire companies are staffed variably throughout the United States, with four members being common in metropolitan areas and less staffing (likely three members) in smaller jurisdictions with full-time firefighting service. In 2019, however, it was reported that 67 percent of the United States is still protected by volunteer firefighters.[38] Within the context of this thesis, what this means is that firefighters responding to a house on fire will have varying skill/training/expertise wayfinding in smoke and may be required to wayfind as a member of a smaller team and may even do so alone.

Firefighters in many fire departments are expected to perform tasks that larger fire departments assign to separate units. For example, in areas with limited staffing, firefighters are often expected to perform fire suppression, search, and ventilation. They often work through multiple SCBA bottles. Larger fire departments have the benefit of additional personnel. Taken together, staffing levels and response times have serious implications for civilian survival and firefighter safety within a burning house.

Engine Company: Engine companies apply water to stop combustion. Most-often, this is done from inside the burning building – from hallways and inside compartments (rooms). This task performs another, equally critical function – to protect those trapped from what is burning. Firefighters assigned to engine companies stretch lengths of hose, either 1.75" or 2.5" in diameter (for smaller and larger fires respectively), to extinguish the fire. In general, an engine company has a crew of three to four members – the company officer, apparatus operator, and two firefighters.

Image 1.6 Engine Company. John Odegard photo. Seattle Fire Department photographer.[56]

Ladder Company: A ladder company's tasks are search, rescue, and ventilation. Firefighters assigned to ladder companies search ahead of, and often in conjunction with, the engine company to find the location of fire and rescue any victims that may be trapped inside; they throw ladders of various sizes to rescue those trapped above a fire; and they ventilate smoke by opening windows or cutting holes in the roof. Each ladder company has a crew similar to engines of three to four members – the company officer, apparatus operator, and two firefighters (one of which may be a tillerman, if the fire department uses tractor-drawn aerials).

Image 1.7 Ladder Company. John Odegard photo. Seattle Fire Department photographer.[57]

Incident Command: The Incident Commander (IC), as they are referred to by firefighters, is tasked with coordinating operations at an incident. The IC determines incident priorities and tactics, directs, and supervise overall operations at an incident by assigning units to various tasks to bring the incident to a conclusion. The IC is typically the highest-ranking supervisor in charge but may also be a company officer at the rank of Captain or Lieutenant in some agencies. They assume a role that seeks to track the location of units operating on scene. They often have a broad "big picture" focus.

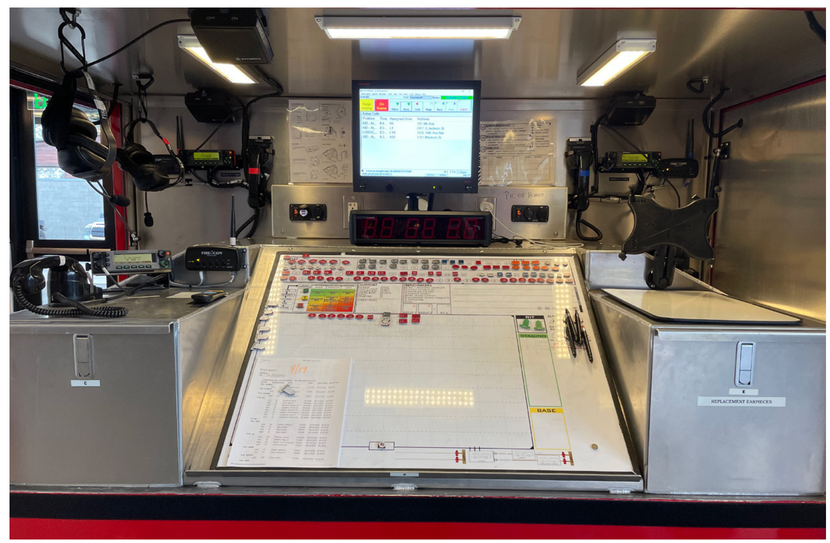

Image 1.8 Incident Command vehicle. Jordan C. Legan photo.

Company Officer: Firefighters assigned to an engine or ladder company are supervised by a company officer (an immediate supervisor), typically a Captain or Lieutenant. On engine and ladder companies (and certain other specialty firefighting units not discussed here), each of the riding positions (officer, driver, firefighters) have an area of responsibility and perform specific duties relative to the unit's broader function and the specific task the unit is assigned. The company officer is the primary decision-maker and must communicate with other firefighting units regularly.

Image 1.9 Company officers. John Odegard photo. Seattle Fire Department photographer.[58]

NOTE: Most fire departments have additional fire suppression and search/rescue capabilities. For example: technical rescue companies, hazardous materials teams, paramedic transport units, or specialized firefighting units to deal with fires in ships and tunnels. This thesis only addresses the three primary units of firefighting – engine company, ladder company, and the incident commander.

The kind of wayfinding firefighters assigned to engines and ladders practice is task-driven and time-sensitive. Inside a burning building, firefighters urgently perform two wayfinding tasks – to search for (and remove) trapped or incapacitated victims and to find the seat of fire (seat meaning where the fire started) in order to extinguish the fire. *Wayfinding* in the context of this thesis refers to the process of planning an efficient and purpose-driven route from the outside of a burning building to locations on the inside and then back out. Wayfinding, in general, can be thought of as an individual or group problem-solving and decision-making process, one that includes orientation, navigation, and locomotion. A burning house (or any building for that matter) is a unique wayfinding environment that continues to evade serious scrutiny and documentation.

1.6 Understanding the Scope of the Urban Fire Problem

A 1973 report titled "America Burning" shed light on the fire problem in the United States and recommended systematic changes to the record-keeping practices within the American fire service. Before 1973, there was no mechanism in place to collect data to understand the scope of the urban fire problem in the United States. Following the report's release, Congress passed the Federal Fire Prevention and Control Act in 1974.[39] The Act created the National Fire Prevention and Control Administration (NFPCA), now called the U.S. Fire Administration (USFA) and the National Fire Academy (NFA).[40] The USFA collects data "from a variety of sources to provide information and analyses on the status and scope of the fire problem in the United States."[41] This quantitative data is used to "highlight current and emerging trends in fires, including what causes fires, where they occur, and who is impacted the most by fire."[42] Additionally, the USFA analyzes the "circumstances surrounding on-duty firefighter fatalities to help identify approaches that can reduce the number of deaths and injuries in future years."[43]

The USFA created the National Fire Incident Reporting System (NFIRS) to consistently describe fire incidents and record data about the fire problem nationally. NFIRS uses 11 modules to record the *type* of fire, *actions* by firefighters, and the *results*. NFIRS is a *voluntary* reporting mechanism, however. As a result, the data collected by NFIRS today still does not describe the full scope of the United States' fire problem.[44] "In many areas of the fire problem," according to the "America Burning" report, "proposed solutions rest on limited experience, shaky assumptions, and guesswork."[45] The same is largely still true today, nearly 50 years after the report was released to the public. Data collection, public education, research, and training efforts have undoubtedly improved firefighting practice and made communities across the United States safer, but there is still no mechanism to collect data nationally about two critical aspects of the fire problem in the United States.[46] First, there is little to no research and literature supported by quantitative and qualitative data that examines the wayfinding practices of firefighters inside burning buildings. Second, there is no data collection mechanism in place to systematically document *how many*, *where, when,* and *how* civilian victims are rescued from inside burning buildings nationwide.[47] This is valuable, missing information with the potential to influence firefighting training and tactics related to wayfinding in smoke. For example, according USFA, 72.2% of fires occur in residential buildings.[48] In 2020, for example, fires killed 3,500 people and caused 21.9 billion dollars in property damage; that same year, there were 102 firefighter deaths.[49] Firefighters need a systematic method to gather information about *how many*, *where*, *when*, and *how*, civilians trapped by fire and smoke are rescued by firefighters. There currently exists no way for firefighters to definitively know their current practices are effective or how training can be improved.

1.7 Conclusion

Improved water delivery, better protective equipment, self-contained breathing apparatus (SCBA), and research and data collection (to a certain extent) have shaped firefighting practice and made interior firefighting possible and wayfinding in smoke necessary. Technological developments in protective equipment, especially "bunker gear" and respiratory protection (SCBA) have made the modern firefighter safer, but less sensitive to the environment, less likely to recognize conditions that firefighters in earlier eras were acutely aware of, and cumbersome.

Today firefighters often encounter larger, less-compartmentalized houses than in the past. These houses often have increased fuel loads, with many synthetic materials. This can lead to rapid fire spread and toxic smoke propagation. Fires burn faster today and produce increasingly toxic smoke. As a result, the performance of modern floor, wall, and roof assemblies have been shown to contribute to early failure under fire conditions, frequently within the time frame it takes for firefighters to arrive, or within their early operational period. Today, firefighters operate with little margin for error.

Until SCBA technology was perfected, firefighters could only operate inside smoke conditions for a limited time during structure fires. After World War II, SCBA technology gradually became available, but even as late as the 1980s, SCBA use was slow to be accepted among the ranks of firefighters, who at that point had become accustomed to charging inside smoky buildings with no respiratory protection. Technological improvements industry-wide shifted the firefighting paradigm allowing firefighters to travel deeper into burning buildings, and to remain inside for longer periods of time. These improvements solved one problem but led to another. This has made the need for effective training of firefighters to wayfind in smoke especially acute.

One of the greatest challenges related to firefighting practice today is articulating a fire department's value to society in a quantifiable manner. The reports currently generated by the fire service at large do not tell the complete story of a fire department's capabilities, training, operational performance, or the true scope fire problem within the United States. Even with technological advances and efforts to collect data, the fire service is often unable to quantify its knowledge and experience to determine its effectiveness (or in some cases, its ineffectiveness) and convey its value to the general public.

For many years, firefighters have learned much of what they need to know through perpetuated myths, through anecdote, and through one's personal experience. They have been exposed to plausible storylines developed from experience inside burning buildings. New firefighters are first initiated into the ranks of smoke eaters through stories told by other firefighters at the dinner table. Over time, these experiences become a tool, or template, for future actions. Using their own unique language, firefighters construct "*vignettes"* which are part description and narrative mixed with jargon and shorthand, often without a beginning, middle, or end. It is not surprising that storytelling persists in firefighting practice because it is the fastest way to convey information and experience — with little explanation. Those outside the society might find the stories crude, harsh, and abrupt, but they are designed to communicate information a firefighter needs to be successful. They operate as a series of warnings that connect the ordinary world to the extraordinary one. The stories help explain things that are likely to make little sense to an outsider.

Communion over a shared meal, the potential for great sacrifice, and literal "baptism by fire" bond firefighters together in ways to which much of contemporary society can no longer easily relate. The reality is that finding one's way inside a building on fire is a hot, dirty, disorienting, and potentially deadly ritual. However, stories told around the dinner table do not fully, objectively, or empirically capture the scope fire problem and what firefighters come to know (or fail to notice). They do, however, offer a window into how firefighting practice has changed to meet challenges of the day and what might be done in the future to address new ones. Novice firefighters are indoctrinated to firefighting culture through stories filled with "contextualized knowledge in the form of mental models" and learn to apply these mental models in context by practicing their own recognition, mental simulation, and storytelling ability. [50] To that end, the stories firefighters tell are a valuable, largely unstudied wayfinding tool. Stories, then, provide a "cognitive template, a paradigm for segmentation, that guides both the production and the interpretation" of knowledge and experience related to wayfinding (and other tasks).[51] Storytelling marks another way to capture and share experience about this specific firefighting practice, one that firefighters seem to use quite extensively.

Firefighters likely developed their oral traditions out of necessity. In the past, firefighters typically had a deep understanding of the environment, due to the frequency with which fire occurred in cities. This is no longer the case in many cities. Today, a significant part of a firefighter's experience comes from training and stories because there are fewer opportunities for firefighters to confront uncontrolled fire. Actual fire conditions are difficult to reproduce and exposure to uncontrolled fire was once a common human experience, has become less common with improved building technology and improved safety features for residential electrical systems, household appliances, and the like. (Firefighter training in smoke and with live fire is a relatively recent invention). The next chapter examines how firefighters are trained to perform this dangerous work (and indoctrinated into the society).

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CHAPTER TWO

Training Firefighters

"In the beginner's mind there are many possibilities, but in the expert's there are few."[1]

– Shunryu Suzuki

2.1 Introduction

Society has come to expect firefighters to understand a wide-variety of knowledge domains – from human anatomy to the anatomy of buildings, from electric vehicles to a building's electrical and mechanical systems. Fire departments have become the default emergency response providers across the country for a multitude of fire and non-fire problems. Their areas of responsibility have expanded considerably over the years. Today's firefighters are "all-hazards" first responders, who provide "emergency medical response, fire suppression, technical rescue, hazardous materials emergency mitigation, response to active shooter/hostile events, fire inspections, public education, investigation, community training," and respond to other emergency situations that threaten life, health, and property.[2] Firefighters are expected to assess volatile, uncertain, complex, and ambiguous problems rapidly (within minutes), and bring them to a successful conclusion often in 20 minutes or less.[3] Firefighters today are asked to carry and maintain bodies of knowledge not necessarily relevant to firefighting practice – to wayfinding in smoke. Increased responsibilities affect firefighters' abilities to process information, remember this information, make decisions, maintain focused attention, function as a team, and carry out skilled motor performances to bring these emergencies to a close. Firefighting may be the only industry that does not go "out-of-service" to practice.[4] As a result, it has become increasingly difficult to train firefighters in all the disciplines in which they are expected to be proficient in between emergency calls and other administrative duties. As a result, skill proficiency is often diluted — this is evident specifically in skills such as wayfinding in smoke.

Broadly-speaking, outcomes in firefighting must be understood within the context of this increased responsibility. Human performance in acutely stressful, time compressed, and sometimes life-threatening environments like a house fire challenge firefighters' capacities to recognize, organize, and act on information quickly. There are volumes of evidence that an individual's psychomotor skills decay and perceptual and cognitive functions are impaired under high levels of acute stress, time-pressure, and physical and mental activity found in these kinds of environments.[5] Skill degradation also occurs with groups of firefighters as they face "mission creep." The term is derived from the military where forces move from "well-defined or achievable missions to ill-defined or impossible ones."[6] Burdened by a myriad of other expectations, firefighting, particularly wayfinding in smoke, remains one of the most-important and fundamental tasks firefighters are expected to perform – and one of the most-dangerous. When firefighters are asked to find their way inside a burning building, one must recognize that this task requires "higher-order cognitive processes and the physical execution of motor skills" inside a dynamic environment with potentially fatal consequences.[7]

The uniquely chaotic environment of each fire can overload the senses and hinder decision-making. Part of this challenge is a basic lack of orienting information. Firefighters rarely have the benefit of prior knowledge of many of the fire buildings into which they enter. This chapter explains how firefighter training is organized with the specific purpose of highlighting how firefighters are currently trained to perform this task. The nature of firefighting requires that firefighters adopt a bias for action, meaning that training conditions firefighters to act very quickly, often with little or ambiguous information. At the same time, firefighters are expected to recognize when success becomes impossible, and their initial assessment of a situation must be changed or abandoned. But interestingly, they are not trained to do so. Given the unknown challenges they will face, firefighters should be taught to remain flexible enough to abandon a plan of action when success becomes impossible. Nowhere is the requirement for flexibility and adaptation to uncertainty more apparent than when firefighters are called to search a house filled with toxic smoke. Wayfinding in smoke is not an innate skill. One must be trained to do this work. Firefighting practice has evolved from a haphazard response by members of the community to a response by trained firefighters with training programs and relatively uniform standards for qualification.

2.2 Wayfinding and Decision-Making

Wayfinding in smoke is fundamentally a problem-solving and decision-making process. In order to reach the target destination, one makes a number of decisions of varying complexity regarding orientation, navigation, and locomotion. Successful wayfinding (i.e., one's ability to reach a destination and return safely) depends on several factors, including the complexity of the environment, one's cognitive ability (including state of arousal), spatial knowledge, training, and memory. In *Reductionism in Art and Brain Science*, renowned neuroscientist and Nobel Laureate, Eric R. Kandel writes "studies of learning and memory reveal that our brain has evolved highly specialized mechanisms for learning, for remembering what we have learned, and for drawing on those memories – our experience – as we interact with the world."[8] Firefighters, the focus of this thesis, have been shown to rely heavily on memories of past experience to problem solve and make decisions under time pressure in acutely-stressful emergency situations like a fire. However, research into firefighting problem-solving, decision-making, and firefighters' perceptual, cognitive, and memory processes practices remains relatively limited.

A notable exception is the research by psychologist Gary Klein and researchers Roberta Calderwood and Anne Clinton-Cirocco, who shed light on human decision-making in 1989, by studying how firefighters make decisions on the fireground. They introduced the *Recognition-Primed Decision (RPD) Model.* The RPD is a type of naturalistic decision-making (NDM) that can be summarized as "decision-making grounded in experience-based intuition and recognition rather than in a deliberative comparison of several courses of action."[9] Since its introduction, significant empirical evidence supports the use of RPD by practitioners from wide-variety of knowledge domains – from emergency medicine to adventure athletes and chess masters. The work by Klein et al. draws from ideas presented in classic research by William G. Chase and Herbert A. Simon in 1973, related to "chunking theory," which explored pattern recognition, intuition, and skilled performance in chess masters.[10]

Klein et al. studied firefighters' decision-making to create this model. Because of that, the RPD is a useful starting point for the following discussion about how firefighters are educated. The RPD has been shown to have three variations (see Figure 2.1):

Use a prototype solution – Facing typical situations where information is rapidly available, one decides according to a mental model of what may have worked in the past.[11]

Create a storyline – Facing situations that do not correspond exactly to a typical situation or that intersect several typical situations, one quickly identifies the differences (or anomaly) between the situation at hand and a typical one and builds a mental story based on one's past experience.[12]

Use mental simulation/imagery – When a situation is recognized, but several actions can be implemented, different options are considered by rapidly simulating outcomes in one's imagination – *without comparing them.*[13]

Firefighters rapidly assess the scene and then wayfind in smoke with little to no advanced preparation. There is little time to integrate, evaluate the importance of, and compare the fragmentary sensory information gathered by multiple sensory systems – visual, somatosensory, vestibular, auditory, and proprioceptive.

At every fire, firefighters face the "experience of being thrown into an ongoing, unknowable, unpredictable streaming of experience in search of answers to the question, *'what's the story?'*"[14] In the chaotic fire environment, Klein et al., showed that firefighters *use a prototype solution*, *create a storyline*, or *use mental simulation/imagery* to make critical decisions. Firefighters – whether one is novice or expert, inexperienced or experienced, or just out of practice – must be trained to recognize cues and make decisions in this environment. It is with this essential context that this chapter proceeds.

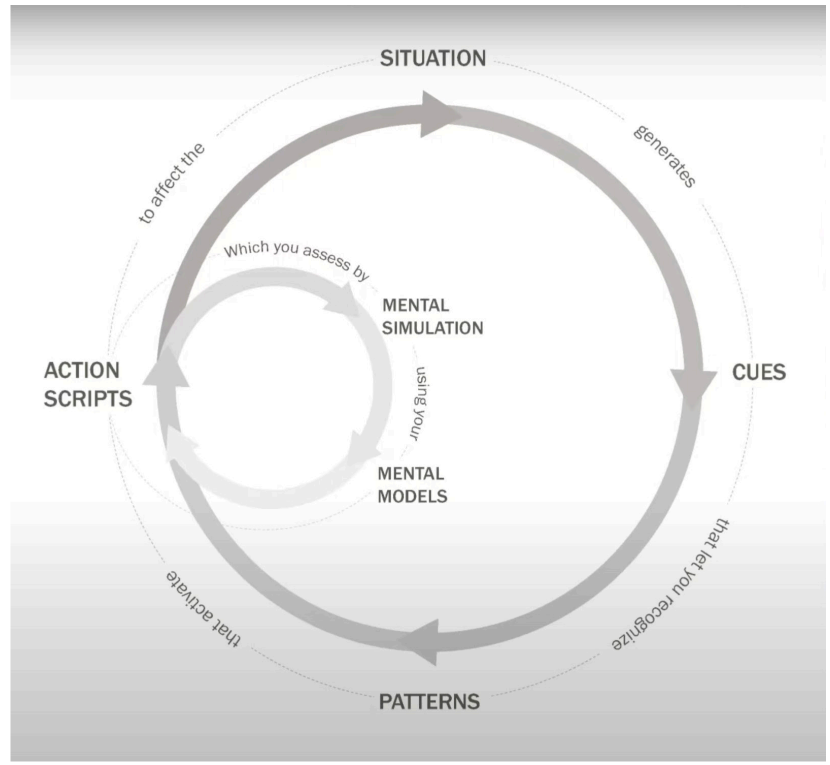

Figure 2.1 The Recognition-Primed Decision Model (RPD).[40]

2.3 Toward a Minimum Standard

A firefighter's education, especially of fire behavior, decision-making, and psychomotor skills in the United States varies geographically and generationally and can vary widely within the same fire department. Today, minimum firefighting standards (including training standards) are established by the National Fire Protection Association (NFPA). Prior to 1974, no national standards existed to guide firefighting practice. The NFPA standards provide a basis for consistent comparison. The NFPA develops consensus documents that outline widely accepted standards of care and operations for certain firefighting practices for professional and volunteer fire departments. They are also voluntary, as the NFPA has no enforcement capacity. There exists no entity to ensure compliance by fire departments and jurisdictions when these minimum standards are adopted. The NFPA standards are adopted (at will) by fire departments which then use the standards to "determine that an individual, when measured to the standard, possesses the skills and knowledge to perform as a firefighter."[15] The NFPA standards documents outline the minimum job performance requirements (JPRs) for career and volunteer firefighters whose duties are primarily structural firefighting in nature – that is, fighting fires in buildings. The NFPA has published more than 300 consensus codes and standards relating to many of the types of emergencies firefighters encounter.[16]

According to the NFPA,

> Each JPR consists of the task to be performed; the tools, equipment or materials that must be provided to successfully complete the task; evaluation parameters and/or performance outcomes; and lists of requisite knowledge and skills one must have to be able to perform the task.[17]

The original purpose of the NFPA standards was to outline requisite knowledge that those who engage in firefighting activities should have and provide a way to determine whether or not a candidate is qualified. Over time, the NFPA's purpose has changed, and its sphere of influence has grown. Today, the NFPA JPRs have become the *de facto* learning model for the American fire service – a purpose for which they were never designed for and one that has serious pedagogical implications for firefighters.

Known informally by firefighters as "skill sheets," the JPRs are void of essential context and are organized/formatted as task checklists that do not represent how adult learning, psychomotor skill acquisition, and decision-making actually takes place. Trainees are instructed to memorize these different JPR checklists and practice the skill in sequential order, then the student is evaluated on how they perform the skill. In Washington State, for example, firefighter trainees have 59 different practical skills JPRs to learn. On average, each of these JPRs has a dozen (but often far more) bulleted steps.

NFPA Standard: 1001, 2019 Edition	**JPR:** 4.3.9	**Skill Area:** Fire Ground Operations: **Conduct a search and rescue in a structure**				
Task: Conduct and complete a **primary search** of a simulated IDLH environment, locating and removing all victim(s), while operating as a member of a two-person team and using an attack line.						
Conditions: Given a search and rescue scenario, an area of obscured visibility, a team member, an assortment of forcible entry tools(s), a hose line or guideline, hand light, portable radio, and in full protective equipment with SCBA, the candidate shall demonstrate the ability to:						
Performance Outcome: The candidate shall demonstrate the necessary skills to conduct a primary search, covering as wide of an area as quickly as possible, removing the victim(s) to designated safe havens, and maintaining team integrity and communication.						
No.	**Task Steps**		**First Test**		**Retest**	
			Pass	**Fail**	**Pass**	**Fail**
1.	Properly wear full protective clothing and SCBA on air and ensure team member is also in full protective clothing and SCBA on air		☐	☐	☐	☐
2.	Size up the problem, assess area for tenability and select the appropriate tool(s) and equipment		☐	☐	☐	☐
3.	Ladders are correctly placed for assignment (if required by scenario)		☐	☐	☐	☐
4.	Correctly open all doors (feeling for heat and opening slowly, keeping control of the door) or windows		☐	☐	☐	☐
5.	Establish and maintain an effective search pattern		☐	☐	☐	☐
6.	Search in a body position appropriate for conditions (e.g., crawling, walking)		☐	☐	☐	☐
7.	Maintain team communication, safety, and integrity		☐	☐	☐	☐
8.	Use hose line or guideline effectively		☐	☐	☐	☐
9.	Find and correctly remove all victims **CIRCLE Victim(s) Rescued:** a. Person without Respiratory Protection b. Firefighter with FUNCTIONING SCBA c. Firefighter with Non-FUNCTIONING SCBA		☐	☐	☐	☐
10.	Complete the search		☐	☐	☐	☐
11.	Properly wear full protective clothing and SCBA on air and ensure team member is also in full protective clothing and SCBA on air		☐	☐	☐	☐
Overall Skill Sheet Score			☐	☐	☐	☐
Candidate Stop Safety: Yes ☐		**Equipment Stop Safety: Yes** ☐				

(CONTINUED ON THE NEXT PAGE)

Image 2.2 This is an example of the typical "skill sheet" for search and rescue inside a burning building. Jordan C. Legan photo.

Prior to being tested, a trainee may only get 4-5 repetitions on a particular skill before they are tested on it. Firefighter educational models based on NFPA JPRs are commonly derided within firefighting circles. Anecdotally, firefighters seem to prefer on-the-job, hands-on education.

The varied education firefighters receive can be partially attributed to a number of things: firefighters do not go "out-of-service" to train; the lack of professional trainers, coaches, and educators; the compressed time frame within which firefighters are trained; and the use of a number of inconsistent firefighting manuals within the industry since about 1978. Before 1978, comprehensive firefighting manuscripts were less-likely to be in circulation and in use industry-wide. Today, four manuals predominate and establish the academic basis for firefighting education in the United States. In addition, likely due to the volunteer origins of the American fire service, there is no unified learning model to meet performance objectives outlined by the NFPA. For example, firefighting training models differed in scope, content, duration, and delivery in Seattle, Washington and in Fairfax County, Virginia, two of the jurisdictions this author has extensive first-hand experience in. Current firefighter training industry-wide produces a rigid, checklist-dependent firefighter. This proves to be problematic in the dynamic, acutely stressful and time-compressed environment in which firefighters operate. While national consensus standards are helpful, jurisdictions are still left to train their firefighters as they see fit which results in a fragmentary response to a familiar, common problem – fire in buildings. The NFPA has succeeded in drawing attention to the need for a metric to measure firefighting practice nationally. However, the American fire service lacks an adult learning model to help fire departments achieve the goals outlined by the NFPA. They lack a training model that takes into account how adults learn psychomotor skills *and* the influence the external environment has on decision-making. Wayfinding happens inside burning buildings, yet this aspect of firefighter training remains largely unstudied. This thesis is an attempt to draw attention to how the built environment affects wayfinding in smoke.

2.4 Educating Firefighters

Knowledge about firefighting, brain science, human performance, architecture, and education often exist in separate silos. Researchers who study volatile, uncertain, complex, and ambiguous environments report that decision-making, like required in wayfinding in smoke, requires "numerous higher-order cognitive abilities" such as inference, reasoning, situational awareness (SA), problem-solving, and is "performed under conditions of extreme stress where the limits of human behavior and achievement are being continually challenged and extended."[18]

To a certain extent, firefighter training seeks to circumvent human perceptual and cognitive limitations, specifically of working memory (WM), and automatize behavior. Certain skills are trained until they become somewhat automatic, developing reflexive habitual response pathways. Some skills lend themselves to developing reflexive habits, others do not. With practice, throwing a ladder, forcing a door, or stretching a hoseline are examples where performance becomes somewhat unconscious. Educators successfully train firefighters to perform these skills competently. Perceptual and cognitive competencies, skills also required of firefighters, however, lack the same emphasis in training. This is a gap this thesis seeks to address.

Wayfinding presents a unique challenge to firefighter educators. Wayfinding in smoke requires that firefighters keep knowledge about the environment organized and readily accessible. Wayfinding in smoke cannot be completely reduced to habituated responses. "Blindly" relying on a reflexive habitual response while wayfinding in smoke increases the likelihood of disorientation. Wayfinding integrates perceptual, cognitive, and psychomotor skills, thus is difficult to train. It is the most-complex decision-making task firefighters perform on the fireground and it is the least-understood. While not a scientific study of perception and cognition, this thesis will address certain aspects of the complicated processes that underlie firefighters' ability to wayfind in smoke. At issue in this section is how firefighters are taught to perform this high-level skill.

Firefighter training at all levels, industry-wide, is non-standardized, meaning that there are wide variations in how firefighters are educated, this problem is especially evident in wayfinding in smoke training. While nearly all fire departments in the United States teach from a similar basic curriculum, as outlined by four primary firefighting manuscripts, and rely on NFPA JPRs as a framework for training motor skills, there is no unified national "model" for adult psychomotor skill acquisition and decision-making related to wayfinding.

High-performance domains such as emergency medicine, music, the United States military, elite athletics, and Olympic sports, all have integrated learning models that provide educational blueprints the American fire service can adapt and put into practical use. The training models in use within these fields have proven to be successful largely because they direct one's "focus of attention to task-relevant cues and away from irrelevant cues."[19] They provide training on the mental aspects of high-performance and create flexible decision-making processes and frameworks. Within all of these occupational environments "time is limited and information is scarce or even absent, and decisions are still urgently required."[20] The same can be said for the environment firefighters operate in most often – the burning house.

In each of the example cases, practitioners are trained to develop a specific toolbox of mental skills including "mental rehearsal, mental practice, situational awareness, self-regulation, and positive self-talk, among others."[21] Because firefighters cannot see inside a burning building, wayfinding in smoke places a significant demand on perceptual and cognitive processes within the brain. It is both a mental and a motor skill. Siobhan Deshauer, BMus, MD , et al. write in "Mental Skills in Surgery: Lessons Learned from Virtuosos, Olympians, and Navy Seals" that without formal education, one "does not automatically acquire these skills; rather, mental skills must be taught explicitly and practiced so that they can be executed effectively with minimal cognitive effort, particularly during times of stress."[22] Mental skills and models have been shown to be essential to describe, explain, and predict situations in complex environments. In this regard, contemporary firefighter training misses the mark completely. It is clear that experienced firefighters develop a number of mental skills and expertise, but there exists no standard method of equipping new firefighters with these tools before they step into the smoke.

Nasser Hammad Al-Azri, a Oman Ministry of Health physician, writes in "How to Think Like an Emergency Care Provider: A Conceptual Mental Model for Decision Making in Emergency Care,"

> Experts are differentiated from novices in several aspects: sorting and categorizing problems, using different reasoning processes, developing mental models, and organizing content knowledge better. In addition, experienced physicians form more rapid, higher quality working hypotheses and plans of management than novices do. Novices

> are especially challenged in this area, since teaching general problem solving was replaced with problem-based learning, as the emphasis shifted toward 'helping students acquire a functional organization of content with clinically usable schemas.'[23]

In other words, practitioners such as firefighters, emergency physicians, soldiers, and others, require a flexible mental toolkit that allow them to make sense of the situation, select appropriate interventions from a confusing stream of information, manage parallel tasks, *and* stay level-headed (see Figure 2.3). In a sense, these professionals are like "circus performers who have to "spin stacks of plates, one on top of another, of all different shapes and weights."[24]

Human performance aspects such as the internal processes of a individual (e.g. their emotional arousal or what strategies they use) have only recently been introduced to firefighters, yet they are of immense importance to decision-making.[25] Al-Azri continues,

> The mental brainstorming that takes place in a matter of seconds is a very valuable and indispensable part of every single emergency encounter. Providers' prior beliefs, expectations, emotions, knowledge, skills, and experience all contribute to the initial approach adopted. Individuals vary in the importance they attach to different factors, and this variation is reflected in the decisions they make. The importance of this mental process is, unfortunately, not reflected in either general medicine or emergency medicine education and research. Traditionally, 'medical education has focused on the content rather than the process of clinical decision making.'[26]

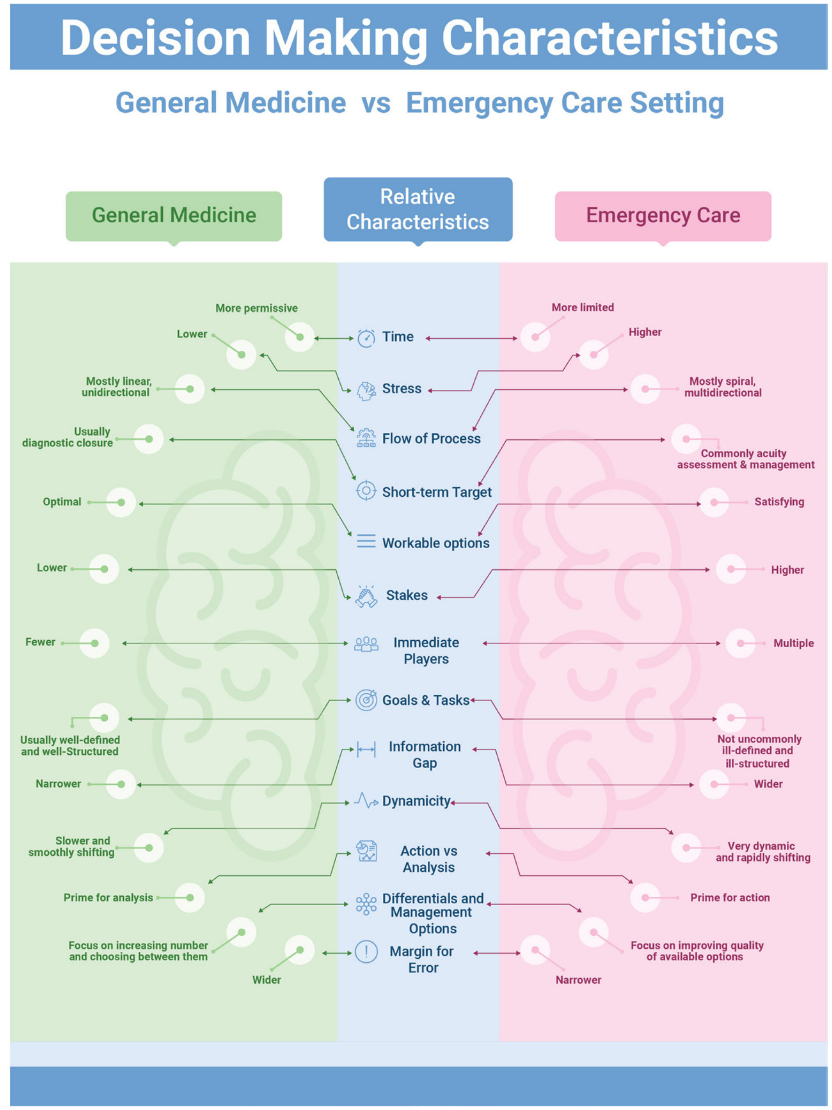

Figure 2.3 Comparing conventional decision-making in general medicine vs. emergency care setting.[41]

This thesis seeks to better organize knowledge about the built environment – firefighters' primary occupational arena. Secondarily, it seeks to help improve wayfinding education and practice, particularly of novices, by bringing an increased awareness to the complicated processes that lie behind wayfinding decisions. By integrating research from these other fields, the thesis introduces firefighters to a number of useful tools to improve the mental skills necessary for successful orientation and navigation within burning buildings.

Current, firefighter education can be classified into three stages – *initial training*, *advanced training*, and *continuing education*. The basic curriculum most fire departments adhere to further separates initial training into discrete subject blocks like fire behavior, fire attack, search theory and technique, ventilation, forcible entry, fireground communications, building construction, and so forth.

The three-phase training regimen followed by most fire departments nationally is as follows:

> **Initial Training** – The first phase, the beginning of firefighter training, is generally referred to as the "fire academy." Trainees (sometimes called recruits) learn basic skills like dressing into the protective ensemble (for time), throwing a ladder, stretching a hoseline, or performing a basic room search, and must demonstrate proficiency through a series of written and job performance review (JPR) examinations. Firefighter recruits spend between 16-29 weeks in this phase of training. During this period, trainees are instructed in basic firefighting theory and practical psychomotor skills. Emergency medical technician (EMT) training is often included. The length and scope of initial firefighting training varies widely by agency. Generally, a subject is given a short period, or block, of focused attention and then the trainees are moved to the next subject. On average, a fire academy delivers 700-1500 hours of instruction. The majority of training hours are spent on the drill ground repeating basic psychomotor skills. Most fire academy training deals with what education researchers and psychologists term *"closed skills."*[27] These are the kinds of skills that are acquired with repetition in a static and predictable environment. Throwing a ladder or stretching hose are two examples. Trainees are allowed a period of supervised practice time, followed by time-constrained practice. On test day, trainees must perform many of the basic skills correctly following the JPR sequence, for time. A stopwatch is applied to nearly everything these trainees do during this phase.

Note: Throughout initial training, students are trained using what psychologists call *"blocked practice."* Here, trainees "practice the same thing repeatedly, each problem employing the same procedure. It leads to excellent immediate performance, but for knowledge to be flexible it should be learned under varied conditions, an approach called varied or mixed practice or to researchers, *'interleaving.'*"[28] Nationally, the initial phase uses a rigid, checklist-based learning model that does not facilitate the kind of flexible knowledge structures and adaptive decision-making that firefighting actually requires. Blocks are rarely revisited and linked to other blocks or skills and placed within a relevant context. "*Closed skills*" are procedure-based and demand few cognitive resources.[29] Acute stress and time-pressure are applied by evaluators who time student performance to ensure it meets the time standards outlined by the organization. Performance during this phase of training is often punitive.

Advanced Training – The second phase commences after graduation from a fire academy, during a period of time called "probation." Here, probationary firefighters, as they are now called, respond to emergencies as part of a crew. Under mentorship of their crew, probationary firefighters practice and are evaluated on their retention of basic skills and new ones they learn during this period. Unlike police officers, who train under the direct supervision of a trained "field training officer," probationary firefighters' training falls largely to their company officer and crew, who may or may not have the necessary requisite training or experience as an educator. The extent of training in this phase varies widely across the United States. Graduates who complete the fire academy and pass the required state written and practical skill exams are assigned to positions in operational companies throughout their respective jurisdictions. These new firefighters are evaluated during a probationary period that is typically one year in length. Some fire departments extend probationary periods in a fashion similar to the apprenticeship programs found in the building trades. During this period, most agencies provide additional manipulative training, instruction on policies and operating guidelines, and test the probationary firefighters periodically. The majority of learning occurs as the result of on-the-job emergency experience. Time-compressed emergency situation does not provide a stable learning environment and the physiological response to acute stress (for example, the glucocorticoid hormones released during stress have been shown to cause memory, a key component of learning, to become shaky) affects the quality of any learning.

Note: In contrast to "*closed skills*," probationary firefighters are now regularly exposed to *"open skills,"* which involve unpredictable environments, active decision-making, and ongoing adaptability in which participants must alter responses in response to the situation.[30] These open skills are the real emergency calls that probationary firefighters respond to with their assigned unit.

Continuing Education – After the probationary period is completed, firefighters have limited opportunities for continuing education. In general, fire departments provide training primarily to maintain certifications and insurance ratings. Opportunities do exist for firefighters to attend training conferences and practical skill training delivered by other firefighters, but usually at their own cost. Few fire departments have the budget to fully support members who seek out additional training. Some community colleges around the United States have fire science degree programs. It represents the only higher-education program geared specifically toward firefighting. Some firefighters do pursue management degrees (bachelor's and master's degrees) at the university level. There exist no university-level degree programs specific to firefighting research, theory, and the practice of fire suppression and search/rescue.

Unlike other disciplines that require extensive study in academia beyond the high school level, the fire service does not. To be clear, there are academic opportunities for professional growth, but those are often pursued only by those who wish to promote into supervisory positions. Few educational opportunities that examine firefighting practices exist within higher education. Some learning opportunities are fostered by the Fire Safety Research Institute (FSRI), which is a non-profit organization within the Underwriters Laboratories (UL). FSRI provides both online and in-person training programs. Through the study of advanced fire science, research, and outreach, the UL-FSRI influences firefighting training. Additionally, there are numerous firefighting conferences and firefighters who teach skills in varying capacities. Even with these, contextually relevant continuing education within the fire service is lacking.

There are a number of notable educational examples, however. One such example is the Nozzle Forward program taught by Aaron Fields, a Seattle firefighter. His program has been implemented in over 270 fire departments (urban and rural, large and small, volunteer and career) and taught to over 45,000 firefighters in the United States and Canada.[31] The Nozzle Forward cites the *Fitts and Posner Stages of Motor Learning* for psychomotor skill acquisition and evaluates student progress and skilled performance using the *Dreyfus* *and Dreyfus' Model for Skill Acquisition: From Novice to Expert*. The conceptual framework behind this thesis is an adaptation based on this author's experience as an educator with the Nozzle Forward. The Nozzle Forward curriculum can be described as,

> An adaptable system of hose line management and fire attack. It is not theory; it is proven on fire-grounds around the country. Adapted from a variety of sources but reconstructed to be based around simple principles that maximize mechanical advantage. The class answers *what*, *why*, *when*, and *how*, and quickly creates a system that can be adapted to fit any engine company from the urban to the rural. The goal of the the Nozzle Forward is to help craft more efficient engine companies by increasing the individuals' competency with their tools and expanding on the conceptual aspects of the fire environment.[32]

In a similar manner, the thesis expands on the conceptual aspects of wayfinding in smoke. What makes the Nozzle Forward curriculum unique is how it expands on the *Fitts and Posner Stages of Motor Learning Model*. The program acknowledges the limitations of stage-based learning models, with respect to working memory (WM), and teaches firefighters to recognize patterns of fire behavior that are shaped by the spatial configuration of the building. In teaching firefighters to recognize interior spatial configurations and respond systematically as they move through them, the program helps firefighters construct and improve decision-making pathways in the brain. The curriculum creates a series of "mental algorithms."

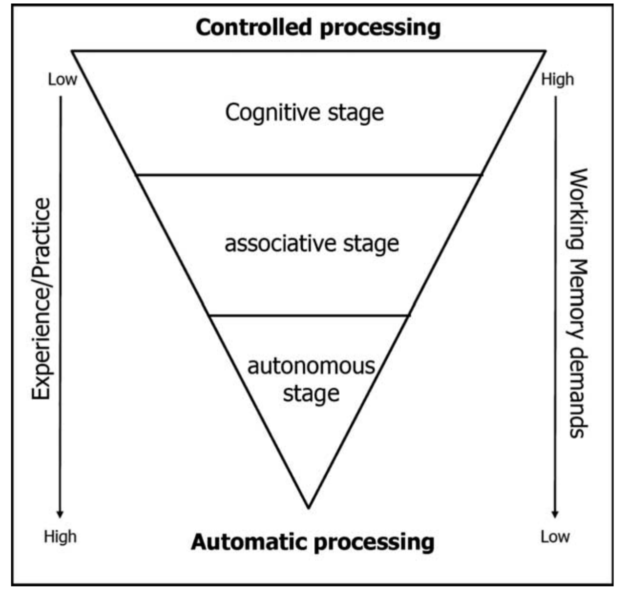

Figure 2.4 The Fitts and Posner Stages of Motor Learning.[42]

The Nozzle Forward curriculum is an exception, not the rule. There is no equivalent training program within the American fire service today. In general, training in the American fire service happens in largely unsystematic ways. There is a need for better training models (ones that include training about wayfinding in the built environment and associated human performance aspects such as visual inquiry, physiology, problem-solving, and decision-making), all supported by quantitative and qualitative research and empirical evidence at the university level and beyond.

2.5 The Lack of Realistic Wayfinding Training

Wayfinding training in the fire service is limited and takes place in spaces that only loosely resemble those found in the built environment. Most wayfinding training firefighters receive takes place in smaller, simpler spatial configurations standard in training facilities constructed by fire departments nationwide. Firefighters are trained in concrete buildings or Conex box facilities that do not resemble anything firefighters would encounter. As a result, most building typologies are never accurately represented in the training environments in which firefighters learn skills. For a variety of reasons including the lack of space, durability, budget, and lack of full-time training staff, most fire department training facilities simply do not accurately replicate the environment in which wayfinding happens. Additionally, many fire departments in the United States do not have their own training facility. These facilities are designed to last and provide repetitive training opportunities. They do well to facilitate repetitive motor-skill learning, or "closed skills." In this regard, they are adequate. Most facilities, however, do not provide an environment that allows firefighters to practice assessing the structure itself. Few facilities allow firefighters to practice higher-order perceptual and cognitive skills required to wayfind in smoke.

Throughout its history, firefighters have recognized the need to practice their skills, but *where* and *how* skills are to be practiced is left largely to chance. This is especially true with wayfinding skills – specifically orientation and navigation. To simulate the visual impairments caused by smoke, firefighters of all eras have practiced search techniques blindfolded wherever they can. Today, firefighters can use non-toxic theatrical smoke to simulate conditions inside a burning building, albeit only loosely. Theatrical smoke does not

Image 2.5 Typical fire department training facility. Jordan C. Legan photo.

Image 2.6 Typical Conex box fire department training facility. Jordan C. Legan photo.

behave the same as smoke from a fire. It does not facilitate the cues (for example, heat, pressure, smoke color, stratification, speed and direction of movement, and density) firefighters would normally use to make assessments and interpretations about fire conditions. Actual smoke and fire conditions are difficult to replicate at a scale and in a systematic fashion that would facilitate true understanding and better, more-accurate decision-making, and skilled performance. Austere training "props" may give novice firefighters a false sense of understanding and inflated confidence, leading to a confirmation bias, in which there is the "tendency to process information by looking for, or interpreting, information that is consistent with one's existing beliefs" or one's previous experience.[33] This is partially due to the familiarity firefighters have with their facility. Novice and experienced firefighters alike often come to believe they understand more about the built environment than they really do. This confirmation bias is amplified by firefighting culture that promotes a superficial understanding of factors that influence the environment in which they work.

Outside on-the-job emergency experience, little time is spent wayfinding in realistic smoke and heat conditions, and even less time is spent doing this inside actual buildings. Many fire departments are allowed to train inside structures scheduled for demolition. For a variety of reasons (e.g., cost, staffing, availability of buildings, local environmental regulations, departmental regulations, etc.) few fire departments are allowed to conduct live-fire training inside acquired structures, even though this is the most-realistic training firefighters can participate in.

Wayfinding inside of a burning house is a particularly strong example where optimized human performance matters a great deal;

Image 2.7 Live-fire training in an acquired structure in Seattle. This kind of training is rare for many fire departments. John Odegard photo.[43]

yet training related to wayfinding remains primitive at best. There exists no research into how spatial configurations and patterns of cues related to types of houses are remembered by firefighters and what influence these may have on firefighters' perceptual, cognitive, and decision-making processes. In this regard, this thesis contributes original scholarship to the body of firefighting knowledge. Successful wayfinding in smoke is contingent on an accurate assessment of the building on fire.

In general, firefighting practice struggles (and sometimes outright refuses) to integrate academic research from other relevant fields of study (for example, education, human performance, physiology, brain science, and architecture, among others) into its training models. Firefighters are resistant to allowing "academics" access into their "blue-collar" world. These fears are often not warranted, however. Rigorous research by other disciplines imparts information, develops tools, and provides resources that has enabled firefighters to make better, more effective decisions that will ultimately save lives and property. One need not look far to see how research has improved fire safety and firefighting practices in the United States. Regardless, there is an opportunity to improve wayfinding education through interdisciplinary collaboration and through architectural design.

Image 2.8 Live-fire training in an acquired structure in Fairfax County, Virginia. Jordan C. Legan photo.

2.6 Developing Firefighting Expertise

It is clear that over time, firefighters develop skill and a form of skilled (expert) performance, but one of the questions posed by this thesis is how firefighters come to understand the environment in which they operate most often – the residential built environment. Wayfinding in smoke involves basic recognition processes *and* the ability to identify complex spatial relationships by certain "rules." For example, rooms inside houses form meaningful spatial relations between one another. This thesis posits that, similar to chess experts who are studied in research on perception (see Chase and Simon, 1973), skilled (expert) performance, decision-making, and brain science, experienced firefighters see the building differently than novice firefighters, quickly and holistically translating what they see into a set of meaningful patterns of cues and strategies. Experts have been shown to develop decision-making and problem-solving strategies based on "an intuitive grasp of situations, ability to recognize relevant features, and a conceptual understanding of underlying principles" of the environment.[34]

According to a paper jointly authored by Nobel Laureate Daniel Kahneman and Gary Klein, both of whom are experts on decision-making, titled "Conditions for Intuitive Expertise: A Failure to Disagree,"

> The determination of whether intuitive (expert) judgments can be trusted requires an examination of the environment in which the judgment is made and of the opportunity that the judge has had to learn the regularities of that environment.[35]

The nature of the occupation allows firefighters many opportunities to notice regularities of houses, specifically in regards to their floor plans. Over time, because of emergency experience and training, firefighters develop a professional and skilled intuition, or expertise about houses (and buildings in general), but this can be improved.

In the paper Kahneman and Klein argue that "professional intuition is sometimes marvelous and sometimes flawed."[36] The professional intuition they refer to, however, need not be so elusive or mystifying. Together, Klein and Kahneman agree that skilled intuition should be defined as follows – "the situation has provided a cue: This cue has given the expert access to information stored in memory, and the information provides the answer. Intuition is nothing more and nothing less than recognition."[37] In *The Neuroscience of Expertise*, cognitive psychologist Merim Bilalic writes,

> The consequence of [this] represents the essence of expertise: attention is automatically drawn to important aspects of the situation. In this way an expert can reduce the complexity of the environment and deal with it successfully, despite limited cognitive resources. They are faster and more efficient, but not because they can examine all the aspects of the problem more quickly than novices. They focus their

> limited resources on the important aspects of the environment, disregarding other less informative elements. Their knowledge enables them to employ qualitatively different strategies from those used by novices.[38]

The question is how to train novice firefighters to recognize the patterns of cues, expectancies, goals, and actions that experts attend to right away. Researchers generally accept that two conditions are required for a novice to gain expertise:

> First, the novice must acquire information in a manner that makes it mentally accessible in the appropriate situations (i.e., the information must be indexed as it occurs in real situations). And second, the novice must practice recognizing cues, expectancies, goals, and action and performing mental simulation in context. Knowing about patterns and using patterns are two different types of knowledge.[39]

Novice firefighters are often overwhelmed by the complexity of the fire environment, and do not yet know how to separate distracting from important information. Wayfinding skill, knowledge, and expertise have been shared primarily through storytelling and on-the-job experience, but these vary widely and are unsystematic so it can be difficult to comprehend in an integrated way. Wayfinding became an essential component of firefighting practice as respiratory protection (SCBA) and protective equipment like "bunker gear" improved. Able to travel further into the smoke, firefighters were forced to direct attention to wayfinding tasks like orientation and navigation. Firefighters wayfind inside buildings, so it makes sense for firefighters to be trained to recognize the regularities of buildings, specifically the regularities of different types of houses. Skilled (expert) performance in firefighting practice is based largely on one's ability to recognize patterns of cues related to the house – *within context*. In this regard, current firefighting educational models miss the mark.

2.7 Conclusion

No situation a firefighter encounters ever replicates itself exactly, so a firefighter's cognitive, perceptual, and psychomotor skills can afford to be somewhat generic. A firefighter's sense of a situation is influenced by their previous experience and the domain-specific knowledge they can draw from to inform their judgments and decisions. Firefighters' problem-solving capability benefits from the fact that fires do tend to burn in certain patterns and houses do tend to repeat spatial configurations. Individually and collectively, firefighters bring to bear perceptual, cognitive, and psychomotor routines to create some sense of structure in this chaotic environment. Experienced firefighters enact firefighting routines based on rapid, holistic assessments of the environment and situation – like chess masters. Firefighters' fireground routines are rehearsed and practiced in training, some to the point they require little conscious awareness.

Unfortunately, current firefighter training largely creates firefighter mimics, not firefighters capable of problem-solving in acute stress in increasingly complicated domains.

Firefighters require knowledge that is organized in such a manner as to be accessible during a fire, when it is needed most. What current pedagogies in the fire service are missing is a set of elemental tools to recognize, interpret, and act on information related specifically to the built environment – to the house on fire. Existing training facilities do not allow firefighters to practice recognizing spatial cues. This is a significant gap in firefighter training today. Different types of houses share certain common spatial characteristics. In general, houses have an explicit organization where one can reasonably expect to find familiar places and one can take familiar paths between these major places. Considered as a series of interconnected places, there is a recognizable order in the configuration of rooms within houses that aids fire suppression and search operations by firefighters. This thesis posits that different types of houses have recognizable patterns of cues and certain repetitive spatial configurations that would be valuable to teach firefighters to recognize and communicate. The next chapter examines principles in human spatial orientation and navigation.

Figure 2.9 Live-fire training in an acquired structure in Fairfax County, Virginia. Jordan C. Legan photo.

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CHAPTER THREE

Wayfinding in Smoke

"The real voyage of discovery consists not in seeking new landscapes but in having new eyes."[1]

– Marcel Proust

3.1 Introduction

Wayfinding can be considered an individual or group problem-solving and decision-making process, one that includes orientation, navigation, and locomotion. A burning house is a unique wayfinding environment. *Wayfinding,* in the context of firefighting, is the process of planning and executing an efficient and purpose-driven route from the outside of a burning house to locations on the inside and then back out. Wayfinding in a burning house, or any building, can be understood in a broader framework. All human cultures have established methods for orienting to features of an environment and navigating from one place to another. Navigation is a "routine, everyday activity and draws upon numerous cognitive functions, including perception, memory (declarative and non-declarative), imagination, language, reasoning, and decision-making."[2] John Edward Huth, professor of physics at Harvard, writes in the *Lost Art of Finding Our Way*, that "all cultures attack the challenge of navigation by reducing the difficult two-dimensional search problem into the identification of a series of waypoints along a route."[3] This chapter focuses on wayfinding as a requirement for firefighting. This chapter emphasizes the house as a wayfinding puzzle because the house is the environment in which firefighters operate inside most often.

The kind of wayfinding firefighters perform is purpose-driven and time-sensitive. Firefighters perform two wayfinding tasks – *to search for trapped victims* and *to find the fire*. What makes firefighting unique in the history of human wayfinding practice is not the threat of physical harm, or the need to be sensitive to subtle perceptual cues, rather it is the speed at which firefighters must orient to the environment and then navigate without clear vision. Under pressure and with impaired vision, firefighters wayfind with little to no advanced preparation. Wayfinding in smoke requires that the firefighter's brain integrate fragmentary sensory information gathered by multiple sensory systems – visual, somatosensory, vestibular, auditory, and proprioceptive – within minutes of arriving on scene. Information comes from optic flow through the eyes, pressure/heat felt through the protective ensemble, one's balance/gravity sense, hearing, and from one's movement. Firefighters orient very quickly to certain spatial and environmental characteristic (specifically fire and smoke behavior) and use this information to choose routes and move through space.

Wayfinding practiced in dark smoke clearly requires navigational skill, but firefighters are often less oriented than they realize and would like to believe, as disorientation is often cited as a contributing factor in firefighter injury and death reports.[4] *Disorientation*, "which is a lack of knowledge of our position relative to other objects in our surroundings, can lead to significant confusion and in some extreme cases, death."[5] Stories of disorientation, plus personal experience by this author, confirm the prevalence of disorientation, even for short periods of time inside a burning building. Firefighters spend a great deal of time "being only one miscue away from complete spatial disorientation."[6] There is little to no research, literature, or qualitative and quantitative data that examines human spatial navigation inside burning buildings specifically. As a result, this chapter examines key concepts in existing human spatial navigation literature and places these within the context of firefighting practice in order to better understand how wayfinding in smoke happens.

3.2 Understanding Firefighters' Wayfinding Problem

A key point to recognize, is the speed at which navigation within burning buildings happens. From the outset, firefighters race the clock to assess the situation and initiate actions to bring the emergency to a conclusion. Firefighters receive limited dispatch information at the time of the alarm and while en-route. After arriving on scene, firefighters will spend less than two minutes gathering valuable spatial information about the building. Very often, this information gathering phase happens concurrently with other tasks. For example, stretching a hose line to a point of entry, pulling a ladder out of its compartment on the apparatus and walking to the building, and conveying information to responding units on the radio. Orientation *always* competes for attention with multiple other tasks and for electrochemical resources in the brain. Another way to say this is: the firefighter's finite electrochemical resources in the brain are rapidly spread thin at critical moments like these.

Whether searching for people, or searching for the fire, firefighters forecast potential locations, plan a route, and then execute an informed search without a full understanding of the environment to be navigated. Firefighters make educated guesses about the interior configuration and structure their actions according to the purpose of the search – for life or fire – from the exterior. Child psychologist Kenneth Hill, in *The Psychology of Lost,* writes that "'knowing where you are' actually means 'knowing the way,' rather than being able to pinpoint your location on a map."[7] The public expect firefighters to "know the way" to reach two separate, but related locations inside the house – the location of people trapped and the ever-changing location of the fire – even if they have never seen (or been inside) the building before.

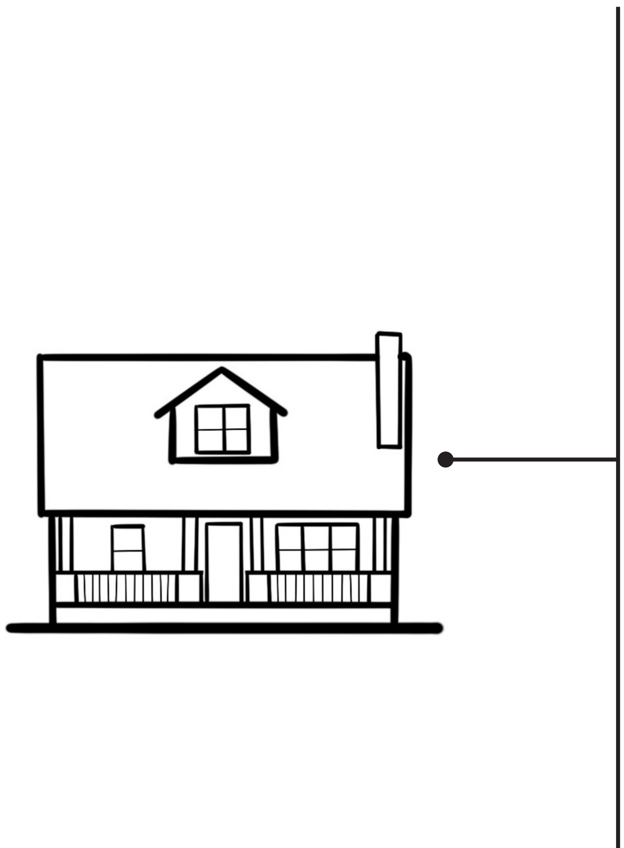
In smoke, vision is limited or often completely obscured. Firefighters are simultaneously separated from the immediate environment by their heavy protective equipment. Visual references on which one relies in sighted movement often become a hindrance in smoke because they are not easily identifiable. As a result, firefighters essentially navigate by feel, by "Braille." Repetition teaches firefighters to unscramble the identity of things in dark smoke, but this can consume valuable time and often directs attention away from orientation, navigation, and situational awareness. As a firefighter navigates deeper into the smoke, it becomes increasingly difficult to maintain a high degree of orientation. One of the methods firefighters are taught to "stay oriented" is to "follow the wall" with a left- or right-hand search pattern, but this technique fails to consider the type of house (i.e., the floor plan), furniture, possessions (i.e., "stuff"), doorways, heating registers, among other things, that keep firefighters from being able to consistently follow the wall to stay oriented. Furniture, for example, "feels" different when the firefighter turns around and retraces their path back out of the building. Additionally, firefighters simultaneously monitor fire and smoke conditions in the compartment (the space in which the firefighter is operating), their position within the structure, and elapsed time – all of which demand attention and brain resources. This demand sometimes exceeds capacity of short-term (working) memory. For example, firefighters assigned to search will travel through and/or between multiple rooms and make multiple directional changes. Every turn forces the brain to update its mental model and store additional information. With vision, integration of new information happens unconsciously. In smoke, it takes conscious effort to keep track of one's position. As a result, firefighters quickly out pace their ability to stay oriented – to remember where they have been. The brain has a finite capacity to remember such details. Firefighters, like most people, often do not monitor "where they are" in a continuing fashion.[8] Disorientation happens when much faster when one loses vision.

When firefighters navigate in smoke, some of their experience may include *poor navigational practices* (i.e., the compulsion to move too fast, overconfidence), *long periods of unawareness* (i.e., distracted by noise or other tasks) and *disorientation* (i.e., failure to continuously monitor one's position). Memory capacity, especially during periods of acute stress, is limited, subject to distortions, and failure.[9] The response to acute stress been shown to enhance *and* impair memory encoding, consolidation, storage, and retrieval, depending on a number of variables. Firefighters' experience is influenced by powerful chemicals (i.e., dopamine, norepinephrine, adrenaline, and cortisol, among others). Chemicals produced by the body during acutely stressful firefighting tasks, combined with a relatively simple training in wayfinding practice, often provide firefighters a chemically induced overconfidence in their wayfinding ability. Because most firefighter training happens in smaller, simpler spatial configurations, it is very difficult for firefighters to transition between navigational paradigms: between frames of reference, between small, easily understood spaces and more complicated real-world environments, and between sighted and visually impaired movement. Training can reduce the stress response if it is done well. Inadequate training will not adequately compensate; in fact, it may make the problem worse by instilling a false sense of confidence or reinforce bad wayfinding practices. These effects make wayfinding in smoke a challenging cognitive leap. Over time, with practice and experience, firefighters develop some level of proficiency in switching back and forth between sighted and vision impaired movement, but this is a learned and perishable skill. Disorientation can quickly exacerbate an already stressful situation, manifesting in changes in heart rate and air consumption, lessening decision-making capacity, lead to erratic behavior, and a loss of sensemaking capability. What is clear, is that firefighters require a flexible "toolkit that allows them to find their way" in smoke.[10]

What follows is a brief example of the fire and smoke conditions firefighters encounter upon entering a house with a well-developed fire. It is illustrative of a number of the wayfinding problems firefighters must address (or at least be aware of) – *within minutes of arrival*. It is with this essential context that this chapter begins.

THE PROBLEMS...

Wayfinding in smoke is made more complicated by the following:



Limited time to make an assessment (often, less than two minutes) before action is required

Time-pressure, acute stress, and competing attentional demands

Confusing, multi-modal sensory information uptake

Physiological limitations (perceptual, cognitive, and work capacity)

Ambiguous, inconsistent, and unsystematic naming conventions for houses

Very limited or no visibility inside the burning building

Limited operating time allowed by self-contained breathing apparatus (SCBA)

Cumbersome personal protective equipment (PPE)

Unknown hazards (i.e., extent and duration of fire, confusing spatial layouts, odd renovations, grow operations, holes, hoarding conditions, among others)

Inexperience and overconfidence

Figure 3.1 A summary of firefighters' wayfinding in smoke problems. Jordan C. Legan illustration.

CONDITIONS

The fire conditions firefighters encounter are based on the fire's location within the building, the extent of fire, and the available oxygen (i.e., whether the fire is "breathing" or not). Thus, interior smoke conditions follow a simple metric – visibility is worse near the fire and is often better further away.

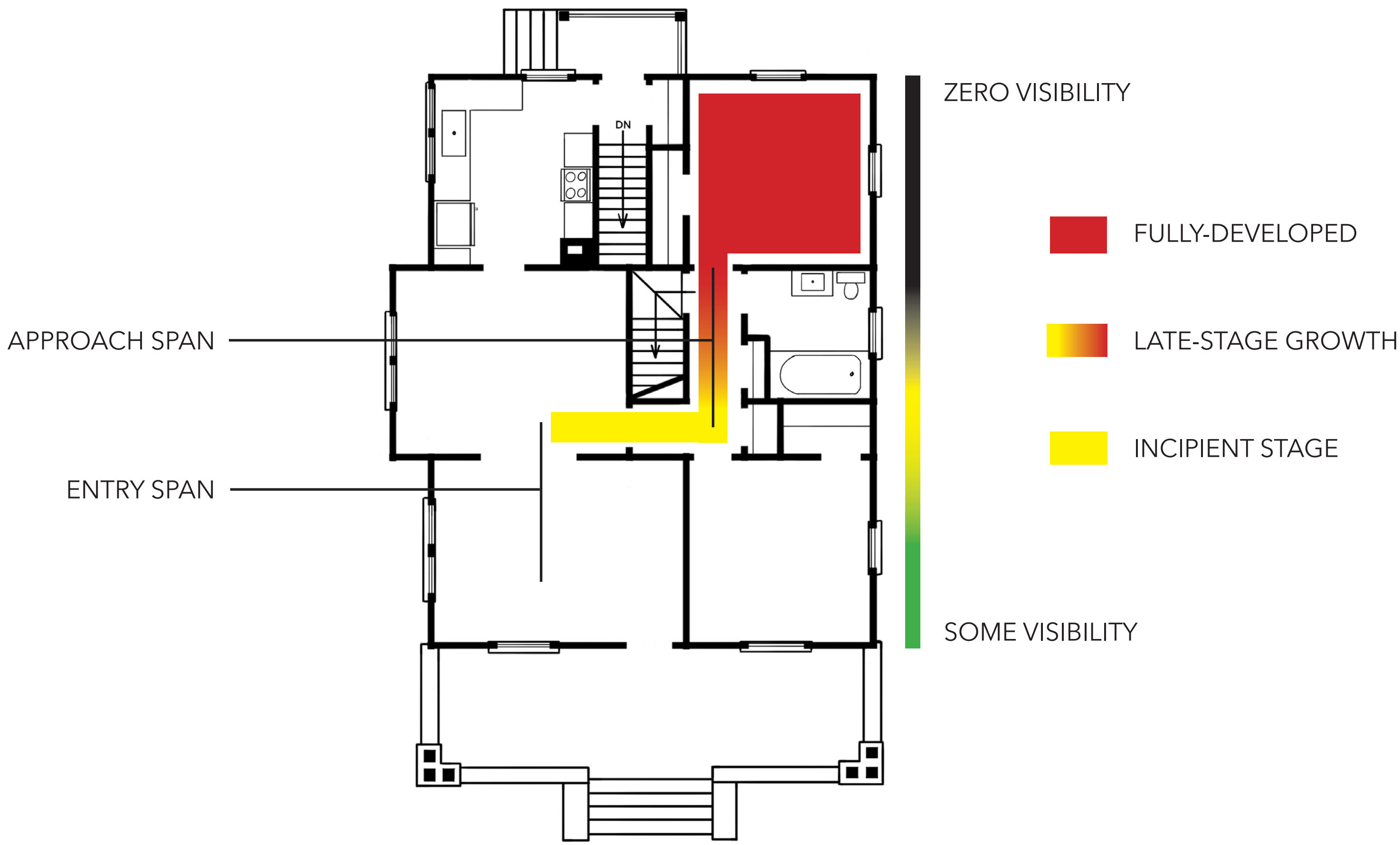


Figure 3.2 Conditions inside the house. Jordan C. Legan illustration.

Image 3.3 Extent of fire and smoke conditions experienced by firefighters on arrival. Screenshot from Stockton Fire Department (CA) video.[82]

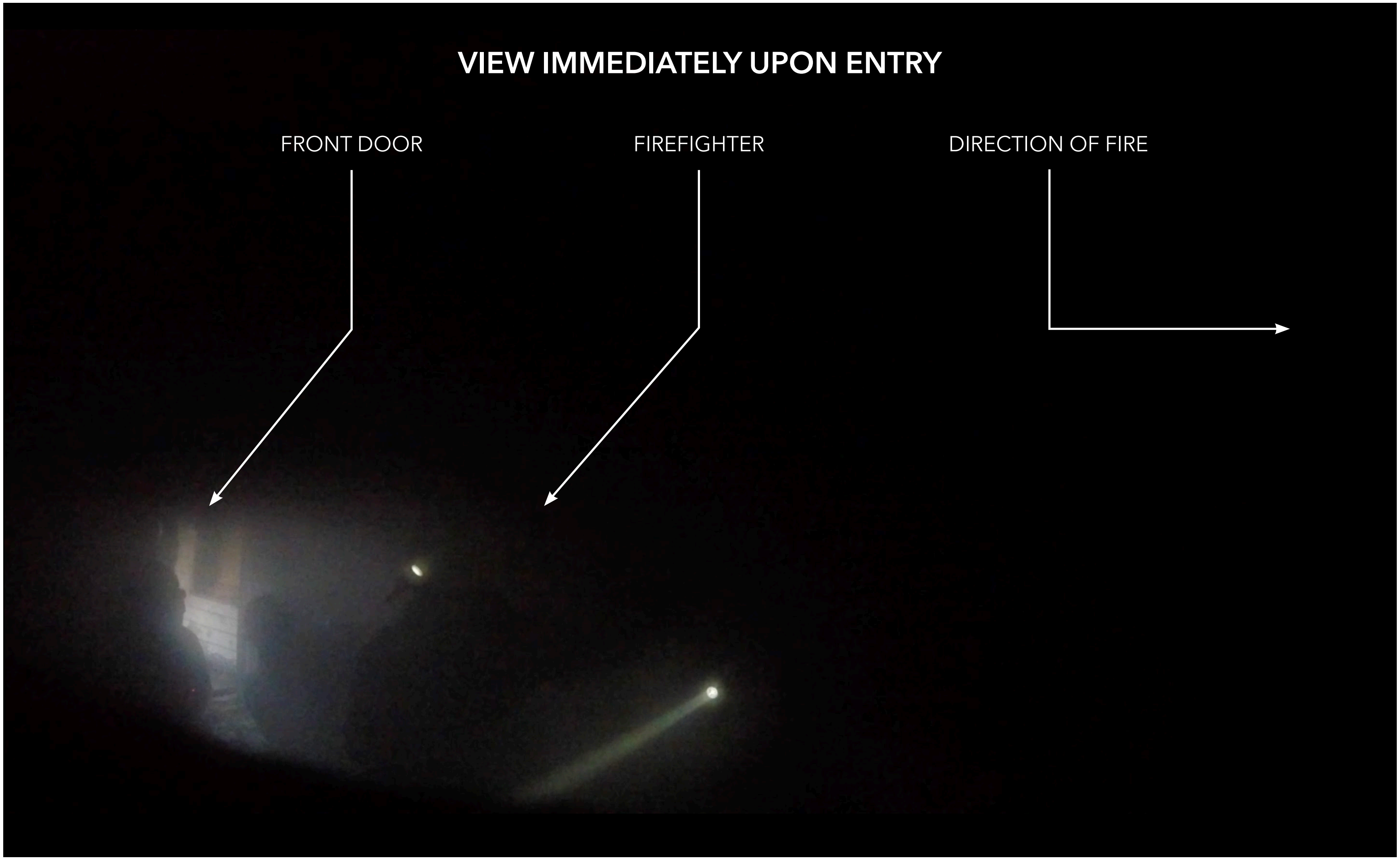


Image 3.4 Fire and smoke conditions immediately upon entry. While not the same fire as in the previous image, the conditions are likely similar. Note how little visibility there is. Nozzle Forward photo.

Image 3.5 Conditions from the beginning of the entry span, *after* the fire received an influx of fresh air from the open front door. This perspective illustrates late-stage growth in this span. Nozzle Forward photo.

Image 3.6 Fire conditions experienced by firefighters from the approach span. The viewer is looking directly into the fully-developed fire room, where the fire is "breathing." Nozzle Forward photo.

3.3 Wayfinding Research

Research into wayfinding has been traditionally performed by (a) anthropologists, who study human cultural practices; (b) by neuroscientists and cognitive psychologists, who study the neural basis; and recently, (c) by architects and associated researchers who study wayfinding in buildings using tools such as space syntax analysis.

Wayfinding literature is generally separated into four categories, or research domains: "(1) wayfinding cognition, (2) wayfinding behavior, (3) individual and group differences, and (4) environmental factors."[11] This chapter synthesizes research from all four domains. It emphasizes research from the field of cognitive neuroscience and places it within the context of the architecture of houses and firefighting practice. Research from the field of spatial cognitive neuroscience, a "discipline of psychology focusing on spatial knowledge," significantly influences this chapter and the thesis overall.[12] Neuroscientist Kate Jeffery, whose research is extensively cited, writes that our recent emphasis on spatial knowledge and its neural basis,

> Has been propelled in part by a recent set of neurobiological discoveries, originally made in rodents, that have profoundly shaped our understanding of how the brain processes space. These discoveries have revealed an entire brain system devoted to the processing of navigable space, and have also shown that this system underpins memory for life events: so-called episodic memory.[13]

In 2014, scientists John O'Keefe, May-Britt Moser, and Edvard I. Moser, received the Nobel Prize in Physiology or Medicine "for their discoveries of cells that constitute a positioning system in the brain."[14] The discovery of a network of cells that underly human spatial navigation ability has been ground-breaking because it has allowed researchers to peer inside these complicated brain processes.

Neuroscientist Arne D. Ekstrom et al. write in *Human Spatial Navigation,* that studying wayfinding in human subjects, especially its neural basis, has been very difficult because "direct intracranial recordings (that is, performed within the skull) are rare and are possible only in clinical situations in which patients already have electrodes implanted for surgical planning (for example, treating epilepsy or removing a tumor).[15] Powerful, non-invasive technology like functional magnetic resonance imaging (fMRI) and virtual reality (VR) now allow researchers to examine the human brain processes that lay behind wayfinding in much greater detail and at a depth not possible even 20 years ago. What researchers know about the neural basis of human spatial navigation is primarily derived from experiments using rodents.[16] The results of experiments using rodents, is presented using models that may not fully capture the complex and dynamic nature of human spatial navigation. As a result, this is an emerging field of study. Research about the neural basis of human wayfinding has not yet been generally incorporated into architectural and firefighting practice but is of enormous value.[17]

In 2021, this author conducted a survey to better understand how firefighters navigate in smoke. In the survey, titled "Wayfinding in Smoke" a respondent was asked to answer Likert Scale questions and respond to open-ended questions about their experience wayfinding in smoke inside houses.[1] Participants in the "Wayfinding in Smoke" survey were recruited via the Nozzle Forward website and its social media pages. Additional participants were recruited by the researcher by email from the ranks of other fire departments. Prospective participants were advised that the study would involve answering questions about wayfinding practices inside a house on fire. This voluntary survey collected responses from firefighters regarding the mechanics of wayfinding in smoke and spatial understanding. Nearly 59,000 firefighters accessed the Facebook post. 2,896 firefighters representing 49 American states and six Canadian Provinces responded to the survey. 51% of those firefighters (or nearly 1,600 firefighters) completed it. Some questions generated nearly 1,000 narratives and descriptions of varying length, about firefighters' experience wayfinding in smoke.

The survey responses call attention to the variability in the ways that firefighters encode, store, recall, and describe this experience. Two themes are consistently represented in the responses. First, firefighters are aware of some patterns of cues and certain spatial features of the houses they wayfind inside. Second, firefighters reported recognizing similarities within neighborhoods. The ability to recognize and articulate underlying patterns of spatial organization could provide a basis for meaningful interpretation and orientation in smoke. For example, when asked whether they could identify patterns of configurations between rooms, 1,316 (or 77.55%) firefighters responded yes. The 1,080 narratives associated with this question, however, show that firefighters have only a loose idea of what organizational patterns actually exist and what to call the house types that have been recorded in the United States. This problem is not isolated to the fire service, one can see examples of this problem in real estate and in architectural history too. Recognition and naming become hugely important when firefighters try to articulate spa-

1 The "Wayfinding in Smoke" survey included a 32-question survey. The survey asked respondents to answer Likert Scale questions and respond to open-ended questions about their experience wayfinding in smoke. The survey was created as part of a graduate research course taught by University of Washington Department of Architecture Professor Alex Anderson. The University of Washington Human Subjects Division (HSD) reviewed the "Wayfinding in Smoke" survey (STUDY00013164). HSD determined that the proposed study is human subjects research that qualifies for exempt status (Category 2). Study approved on April 23, 2021.

tial configurations in mind and to others while navigating in smoke. The use of confusing and unorganized spatial terminology in the responses to survey questions supports the assertion that firefighters lack requisite training to recognize, name, and communicate about houses effectively. In a firefighters' wayfinding tool kit, visual acuity and words prove important.

Firefighters must accurately recognize patterns of cues, interpret ambiguous sensory information, and make decisions under time-pressure and acute stress. It is one thing to be assess a house for sale, design, or historical purposes. It is wholly another to do it when the house is on fire, and then use the assessment to navigate without vision to specific locations inside and then back out.

3.4 Foundational Principles in Human Wayfinding

Navigation can be defined as the "inherently *multi-sensory integration* process that combines multiple cues to accurately find" the way to a goal.[18] One's ability to navigate any environment, depends on one's knowledge of that environment. Human spatial navigational practice regularly taps into high-level cognitive processes that require conscious awareness and the retrieval of knowledge about the environment from memory. Navigation also relies on functions that operate outside conscious awareness in a manner similar to an autopilot, sometimes to the detriment of sensemaking and orientation. These operations are considered habituated responses. Two core components comprise how one navigates; the first component is the "path integration system"; and the second component is one's "memory for the locations of spatial landmarks."[19] Navigation requires that disparate environmental information be integrated quickly into a mental representation that can be acted upon.

Ekstrom et al. writes, "navigation involves a high degree of visual imagery" and visual scrutiny.[20] Regardless of the environment, a navigator must learn to recognize and integrate *internal* and *external environmental cues* to maintain orientation and navigate successfully to their intended destination.[21] *Internal cues* include one's sense of direction and spatial mental models stored in memory, which are referred to as "cognitive maps" or "spatial mental models" in some of the reference literature.[22] Internal cues require one to use "mental estimates of direction and distances over the course of their journey."[23] In the literature, the integration of distance and direction is termed *path integration*. To "keep track of both direction and distance traveled" is a critical component in navigation.[24] Path integration involves integrating information from the "vestibular, sensory, proprioceptive, and motor systems to estimate direction and distance."[25] Using *external cues*, navigators rely on landmarks and spatial configurations as reference points. In studies of human spatial navigation, researchers consistently point to the importance of learning relevant external cues. Firefighters rapidly extract patterns of cues related to the exterior of house on fire (for example, exterior massings, organization forms, patterns of fenestration, size, and arrangement of architectural details, among others) before entering. Once inside, landmarks and patterns of cues are obscured quite often by the smoke, so firefighters rely heavily on "feel" to recognize them (for example, firefighters use walls, doors, windows, type of flooring material and changes between flooring material, floor vents, furniture and appliances, cabinets, and stairs, among others). Using a combination of these cues, sounds, communication between other firefighters, the hoseline, and memory, firefighters find their way to locations inside and back out.

Orientation takes two forms in the human spatial navigation literature (see Figure 3.7). These two frames of reference describe how an environment is captured in spatial memory and subsequently used in navigation. An *egocentric* frame of reference is defined from a point of view one has experienced previously. This frame of reference relates closely to the "axes of the individual's body."[26] An *allocentric* frame of reference, in contrast, is not dependent on a specific view, but rather on cues independent of the "individual's body and perspective."[27]

These two frames of reference are powerful unifying principles in wayfinding and brain science research more broadly. In some literature, an egocentric reference is referred to as "route knowledge," and an allocentric reference refers to "survey knowledge" about spatial configuration. Ekstrom et al. writes:

> Thus, as we first learn an environment, we may acquire knowledge of the names and locations of landmarks, the routes that contain some of these landmarks, and even their approximate topological (two-dimensional, sequential, egocentric) relationship. As we learn more about the environment, we gradually fine-tune all this information and develop more precise allocentric knowledge.[28]

Egocentric *and* allocentric frames of reference appear to shape the navigational strategies navigators use. Ekstrom et al. writes,

> Several different navigational guidance systems appear to operate in the brain. At the most simple level, a system for following repeated habits operates in a non-goal-directed fashion that appears to involve the striatum. A goal-directed system for navigating based on a representation of the environment's layout and vectors to locations within it appears to rely on the hippocampal-entorhinal network.[29]

These two networks "represent an important interplay, even competition, between brain systems involved in different forms of navigation."[30] It turns out that competition between systems for resources is a hallmark of brain function. One forms the basis of a flexible "*place-based*" navigational strategy and the other forms an inflexi-

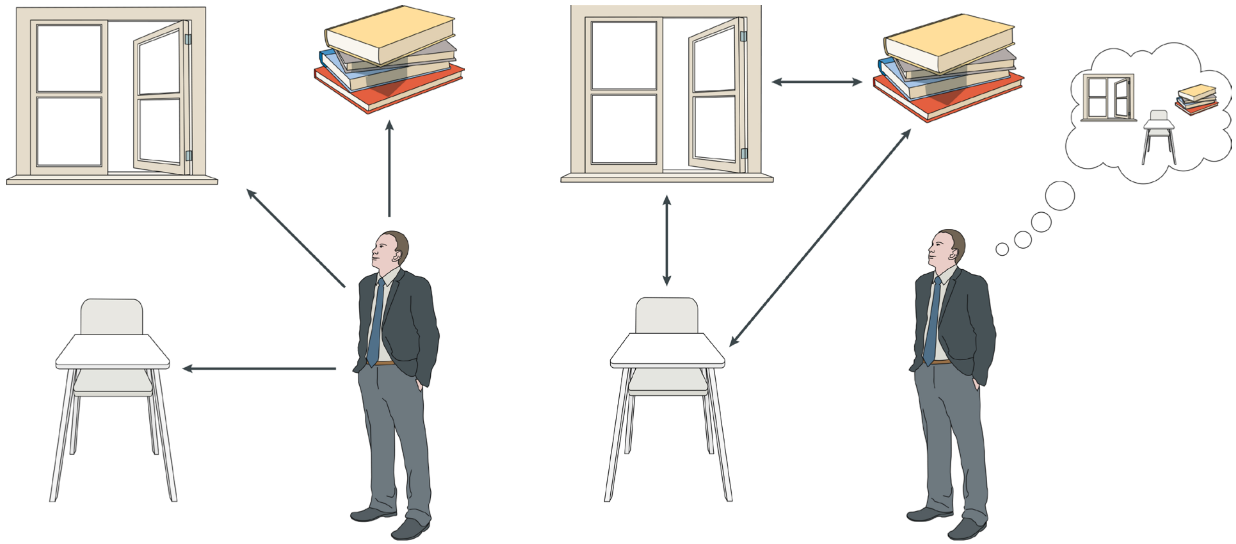


Figure 3.7 *Egocentric* frame of reference vs. *Allocentric* frame of reference. An egocentric frame of reference encodes spatial information from the viewpoint of the navigator. An allocentric frame of reference encodes a navigator's perception of landmark positions relative to other landmarks.[83]

ble habit "*response-based*" navigational strategy.[31] Egocentric and allocentric frames of reference do not exist apart from one another. Ekstrom et al. writes, "it is fairer to say that they form a continuum of possible forms of representations, with most navigational situations involving mixtures of these two different methods of representing space while navigating."[32] Two brain areas (among others, though) are implicated by these strategies – the hippocampus and the caudate nucleus (part of the striatum) – compete for limited attentional resources during navigational tasks.

A *place strategy* (sometimes called a *spatial memory strategy)* "involves navigating within an environment using the relationships between different landmarks and orientating oneself in relation to those landmarks, much like allocentric navigation."[33] This strategy's flexibility comes from the navigator's ability to recognize the "relative positions of landmarks" and that a "target can be reached in a direct path from any starting position in our mental map based on storing this information in an allocentric frame."[34] For example: A ladder company searching for victims inside a burning house often operates independently of the lifeline on which the engine relies on – the hose. The ladder company navigates into and through every room of the house, prioritizing search in those areas closest to the fire first. To add to the complexity, ladder companies can be expected to enter the building from any window or door. They rely on a broad and flexible understanding of the environment offered by the place strategy.

In contrast, a *stimulus-response strategy* (sometimes called a *response strategy*) "involves learning a series of behavioral actions from specific points in the environment that act as stimuli."[35] A *stimulus-response strategy* is used more often by an engine company because they move through the house following the paths of circulation and respond immediately to heat energy and fire by applying water. The extent of their navigation inside is limited by the fire's presentation and their response to it. In many cases, visible fire makes it easier for them to navigate. There are a limited number of variables an engine is concerned with inside the house. The engine is most concerned with paths of travel, stair locations, and places (e.g., compartments). Ekstrom et al. writes,

> A response strategy is inflexible in the sense that it does not allow deriving a novel path to a target location. Furthermore, this strategy is often egocentric, particularly if the series of stimulus-response associations are based on the starting position of the navigator.[36]

It is likely that firefighters assigned to both companies use both strategies while navigating in smoke. Additionally, firefighters develop some level of comfort integrating fire behavior and smoke behavior into their wayfinding decisions. A number of a firefighter's wayfinding decisions become habitual – programmed through training. In some situations, this can be helpful, but in others, habitual response is problematic. For example, if a firefighter always performs a left-handed wall search, there exists types of houses where a right-hand wall search will take the firefighter to the bedrooms more rapidly. The navigator, in this case firefighters, need a flexible toolkit.

One might say that wayfinding in smoke requires a "holistic" approach, one that integrates perceptions, memory, environmental cues such as fire, smoke, and the building, and technology such as a thermal imaging camera (TIC). Methods of confining the fire and search are a function of building geometry, of the articulation of its form, or shape. Kenneth Hill, in his essay "Psychology of Lost," writes that "sometimes people overestimate their knowledge of the spatial layout of an environment," perhaps mistaking egocentric knowledge for accurate allocentric knowledge, "which may make them vulnerable to becoming turned around."[37] It is easy to "get turned around" in smoke when wayfinding requires tracking all direction changes, deciphering ambiguous percepts, and a reliance on memory.

3.5 Learning Unfamiliar Environments

Researcher Anna Charisse Farr et al., write in "Wayfinding: A Simple Concept, A Complex Process," that "wayfinding is an interplay between an individual's characteristics, such as age, gender, cognitive development, perceptual capability, spatial ability, mental and physical conditions, and the characteristics of the environment, such as size, luminosity, signage, and structure."[38] Types of spatial ability essential to wayfinding include "mental rotation, spatial perception, spatial visualization, object location memory, dynamic spatial ability," and mental imagery (i.e., visualization).[39] Firefighters are not all at the same level in terms of ability, skill, understanding of the environment, or experience (teams include novice and expert firefighters). Additionally, other factors influence wayfinding such as, "language, culture, gender, and biological factors."[40] Together, these have been shown to affect how one comes to know and wayfind in a particular environment.

Learning an unfamiliar environment begins with close visual scrutiny, often guided by a more experienced navigator. One can learn a lot about the properties of an environment "simply by remaining stationary and looking around for even brief periods of time."[41] A primary skill in wayfinding practice is observation, recognition, and categorization. In *You Are Here: Why We Can Find Our Way to the Moon but Get Lost in the Mall,* neuroscientist Colin Ellard writes that "to build an integrated view of the layout of the space we occupy, we need to move our eyes ceaselessly."[42] The visual system feeds the brain a steady diet of environmental cues such as: the shape of the built environment, visual patterns, and detailed scenes that it uses to make decisions and predictions as one moves through an environment. The brain specifically seeks out patterns and stores these in mind as representations to speed up retrieval and processing. Because humans are primarily visual beings, what one "sees" is a direct result of how the nervous system functions, an individual's unique perceptual and cognitive processes/filter(s), and what one has been taught to recognize. In firefighting, an equally important part of learning happens by feel alone. Because they often cannot see clearly in the environments they navigate, firefighters cannot come to know their environment without also learning what it *feels* like. The following is an excerpt from an online manual describing how the visually impaired orient to the environment around them:

> Blind students must spend more time exploring space and examining objects to arrive at the same spatial understanding as a sighted person. To interact with the environment (to reach for objects, walk around objects, pass through open doors) the sighted individual uses a viewpoint-dependent representation of the world. From any position, and after each change in position, the sighted person instantly sees how the world has been repositioned, how objects have changed in relationship to movement (the sighted persons

> movements or the objects movements). Blind individuals do not have an instantaneous viewpoint-dependent representation of the world. Blind students must build mental maps of layouts and of routes, and make future projections along the route based on non-visual memories.[43]

Firefighters learn about the environment in a similar manner to the visually impaired. Fortunately, as Eric R. Kandel writes in *Reductionism in Art and Brain Science: Bridging the Two Cultures*, "modern brain science has revealed several regions of the brain thought to be specialized for processing visual information are also activated by touch."[44] This means that the brain seems to develop richly integrated multi-modal representations (in a firefighter's case, visual and tactile) of an environment. Knowing (especially by feel) an environment's shapes, configurations, patterns of cues, and landmarks help direct the flow of attention and function as open inventories; containers into which this kind of information is held and can be acted upon. The skin has various receptors that translate tactile information (pain, temperature, pressure, among others) into electrical signals. All of the human sense organs influence firefighting practice, but of particular interest to this thesis are the operations of and relationship between the visual and the somatosensory (or tactile) systems. *Knowing by feel* connects perceptions distorted by the smoke to volumes of spatial mental models kept in memory. It helps keep the firefighter firmly grounded in the reality of the moment. In smoke, maintaining situational awareness is challenging. This is made more challenging when performed as a team. Shared situational awareness has proven to be problematic in other arenas (i.e., pilots and the military).

Humans have a basic tendency to construct general spatial mental models for any environment. Humans seem to extract generalities from variegated experiences in the world. Ellard writes that "our mind tends to simplify visual scenes. The complexity of real forms comes to be replaced by simple collections of basic shapes, organized according to schemas — sets of rules that dictate how these basic shapes must be fitted together."[45] The mind organizes spatial information into recognizable and informative units or categories. The brain then uses these units of information for understanding and prediction. A schema serves as a mental organizer, retrieval cue, and in some cases, a template for action. The brain uses a reductive approach that involves reducing or atomizing information to separate the useful from the useless; the essential from the non-essential. The brain processes everything by generalizing and categorizing, but the brain cannot establish categories without memory. Harvard educator Shari Tishman, in *Slow Looking: The Art and Practice of Learning Through Observation*, writes that,

> Categories vary widely across contexts, but their basic purpose is the same: they function as a lens to selectively focus the flow of perception on certain features. They operate at a conscious and unconscious level, and it is impossible to imagine human cognition without them. Categories are at work in the expectations, purposes, and assumptions we bring to any experience, allowing us to 'see' certain things rather than others."[46]

Understanding the relationships between the parts of the environment and the whole, and between paths and places is a necessary skill for any navigator. Ellard writes, that while this simplification of space "can help us to manage our memory load, it results in distortions in our maps of space. In our mental maps, the distances between points that are in different regions seem longer than distances between points within the same region."[47] These spatial mental models, similar to "the maps we sketch on napkins to guide our friends around town, are filled with inaccuracies, distortions, and even absurdly impossible spaces."[48] Ellard continues when he says that "our minds treat distance and direction with cavalier disrespect but represent topological relationships with greater clarity."[49] One understands and comes to expect that any environment has certain recognizable spatial characteristics and relationships – an explicit organization where one can reasonably expect to find certain places and that one can take familiar paths between these "familiar" places. The organization of rooms within houses illustrates this point well. Learning to recognize spatial relationships is an important skill firefighters must be taught and practice consistently because wayfinding in smoke is fundamentally about probabilities – it is about knowing what to look for and where to find it.

3.6 The Path Integration System

Path integration is the "process of updating a representation of position based on self-motion information."[50] This system "exists in all of us."[51] Path integration allows humans to "track both position and direction with little training," and it has been shown to work in the absence of visual cues, which is especially important for firefighters who operate in dark smoke.[52] Neuroscientist Kate J. Jeffery writes,

> Path integration is useful because it can take place in the absence of landmarks or other cues to position, needing only a directional reference and some way of measuring speed and time, or (alternatively) distance traveled. It has been used for centuries by human sailors to navigate over featureless oceans, who refer to the process as "dead reckoning" (the "dead" is a corruption of "ded," short for "deduced"). The same principles discovered by sailors have also been discovered by nature, and research over the past century suggests that the majority of mobile animals use some form of self-motion tracking. Biologists have tended to prefer the term "path integration" for this process.[53]

Path integration happens automatically and constantly. The path integration system, however, is also "error prone."[54] And errors tend to accumulate quickly. To combat this, the high-definition human visual system provides “a powerful way of updating our path integration system.”[55] Jeffery writes,

> The importance of vision is that it conveys information from the distant, static outside world, and so is able not just to update a position computation but also to reset it, if the animal becomes disoriented. Indeed, this resetting process may operate continually when landmarks are visible, with dependence on self-motion information, in the form of optic flow.[56]

Inside the burning house, firefighters may be slow to “reset” their brain or may not have the ability to all together, due to the opacity of the smoke.

Firefighters perform a combination of *route following* (i.e., identifying spatial cues and following a “familiar” path by habit), *piloting* (i.e., using landmarks to guide navigation), or *dead reckoning* (i.e., deducing one’s location within the environment). Firefighters use spatial information they gathered from their initial assessment, information from memory, information in the form tactile information, and fire and smoke behavior to navigate. Smoke, however, makes spaces seem larger; distance and bearing estimates are easily distorted; and familiar landmarks and objects often become unrecognizable. To the trained eye, however, smoke does carry some useful information. Its color, volume, density, speed, and pressure can be used to give the firefighter an idea of the distance to the seat of the fire, elapsed time, and one’s position (relative to the fire) within the environment.

With practice, firefighters develop the ability to integrate inferences about the floor plan with sensory information in the absence of landmarks. They also learn to distinguish certain sequences of rooms from the inside, in the smoke. With that comes the ability to recognize decision points inside the environment, form (and make sense of) useful associations. The goal is unambiguous — to rapidly enter the building to save lives and stop the fire, but there has been little inquiry into how firefighters integrate sensory information to orient and navigate. Path integration requires that the navigator pay attention to cues from the environment, cues from self-motion, and incorporate new information continuously. Path integration takes on increased significance when framed as a process of sensemaking in wayfinding in smoke.

Without its primary mode of apprehension (vision), the brain draws from memory spatial, contextual, and experiential information. It constructs an image in mind that may not accurately represent the space the firefighter is operating inside. The further one moves into the smoke, the harder it is to maintain orientation. A brief glimpse of a piece of furniture like a table, the bed, or a fireplace, can situate that firefighter, or “reset” and sharpen the image in mind and to help the situation "make sense." Tactile information can perform the same function. For example, feeling the change from a hard surface to carpet can indicate moving from the dining room to the living room, or from a hallway or bedroom into the bathroom. Cues such as these can reorient one almost immediately, but that same object in a location outside the brain's expectation pushes the firefighter closer toward disorientation, toward a collapse of sensemaking. Disorientation happens on continuum, from instances of no significance to those that can be fatal. For example, in the "Wayfinding in Smoke" survey, 43.79%, or 681 firefighters, responded that they had been disoriented or lost inside a building on fire. This is likely a gross under-count of the actual number given the cultural stigma associated with reporting disorientation. Firefighters pride themselves on successfully wayfinding in smoke, and very often they do, but firefighters still die every year because they became disoriented, which can quickly proceed to being utterly lost, and the rapid depletion of air. Collectively, the fire service (this author included) does not fully appreciate the complexity of wayfinding tasks and just how close one is to becoming lost.

3.7 Sensemaking in Smoke

According to Karl Weick, *sensemaking* "is about labeling and categorizing to stabilize the streaming of experience. Labeling works through a strategy of differentiation and simple-location, identification and classification, regularizing and routinization (to translate) the intractable or obdurate into a form that is more amenable to functional deployment."[57] Thus, sensemaking refers to how individuals and groups "structure the unknown so as to be able to act in it."[58] Deborah Ancona, professor at the MIT Sloan School of Management describes sensemaking as "an emergent activity – a capacity to move between heuristics and algorithm, intuition and logic, inductive and deductive reasoning, continuously looking for and providing evidence, and generating and testing hypotheses, all while 'playing the game.'"[59] Sensemaking (and wayfinding) involves creating a plausible model of a shifting, chaotic fire environment; testing this model with other firefighters through action, and conversation; and then refining, or abandoning the model depending on how credible it is.[60]

Firefighters generally do not wayfind alone – they most-often operate in pairs. Unfortunately, however, some agencies, due to low staffing, task a single firefighter with search/rescue. In the majority of cases, two firefighters wayfind together. One firefighter maintains orientation, while the other searches. However, because each firefighter "sees something different or nothing at all because of the smoke" sensemaking is quickly revealed to be a fragile construction.[61] Firefighters interact in an environment (under acute stress and time-pressure) where there is often a shared situational awareness. It is not surprising to note that there are examples where social wayfinding, as also practiced by firefighters, occasionally goes badly. Individual navigators, as reported by Dalton, "may rely on internal mental capacities only, such as their knowledge and spatial reasoning. By contrast, wayfinders in groups may also have to take into account the preferences of other group members."[62] The kinds of human errors that contribute to failures of communication in the cockpit prior to plane crashes (there are numerous other occupational examples) are similar to ones that cause disorientation in wayfinding, as studied here. They are "invariably errors of teamwork and communication," and sensemaking.[63] Economics professor Carl E. Enomoto et al. considered crises faced by pilots before crashes in "Culture and Plane Crashes: A Cross-Country Test of the Gladwell Hypothesis," write,

> The whole flight deck design is intended to be operated by two people, and that operation works best when you have one person checking the other, or both people willing to participate", says Earl Weener, who was for twenty years chief engineer for safety at Boeing. Airplanes are very unforgiving if you don't do things right. And for a long time, it's been clear that if you have two people operating the airplane cooperatively, you will have a safer operation than if you have a single pilot flying the plane and another person who is simply there to take over if the pilot is incapacitated.[64]

Enomoto writes, "when faced with a crisis in the cockpit, what is needed is strong and direct communication."[65] In many cases, how information is processed and articulated during these crises fails to "convey enough correct information about the urgency of the problem at hand." Architect Ruth C. Dalton et. al. writes in "Wayfinding as a Social Activity," write that,

> Many people have experienced the situation of navigating as part of a pair, whereby each person has implicitly assumed that the other knows where they are going. Each person accordingly but mistakenly assumes a subservient role, only for both parties to eventually realize that neither of the pair are effectively leading, but both are attempting to follow. This situation also highlights the fact that quite often the disparate roles within a wayfinding group are adopted without prior negotiation (i.e., they are assumed or inferred), adding even more complexity to understanding these phenomena.[66]

Little attention has been paid to the roles and organization of firefighting teams particularly those tasked with wayfinding in smoke, alone and as a team. Firefighters, in many organizations, are considered interchangeable, but this presents wayfinding and sensemaking problems. Primarily, that any "crew" of firefighters is likely to have varying experience, skill, training, and understanding of the environment they operate inside. There is also a power, or authority, dynamic in firefighting teams. New firefighters are often paired with more senior company officers.

The culture of silence in firefighting practice that pressures new, often inexperienced firefighters, to stay quiet, even if they have critical information to share. It would not be surprising to hear that while wayfinding, the junior member makes no effort to maintain spatial awareness or help team stay oriented as it moves. The current firefighting culture encourages it. Inside this environment, it would be bad practice to have encountered, for the first time, the disintegration of the team dynamic and sense-making. Clear and concise communication about features of the environment is an essential wayfinding tool. Firefighters would do well to examine how wayfinding is affected by team dynamics.

3.8 Order of Experience on the Fireground

Firefighters are assigned roles that have distinct foci, responsibilities, routines, orientation, and that require different thinking dispositions. Each role also has a specific order that dictates how the spatial characteristics and fire conditions are integrated in mind – how one makes sense of their assignment. The fireground routines establish a perceptual hierarchy, an explicit sequence of operations, from – the *Outside,* the *Inside,* and then the *Topside:*

From the Outside – Firefighters make decisions based on limited views of the exterior of the structure. They make "educated guesses" and predictions about a residential building's era of construction, type of frame system, construction assemblies/materials, potential location of fire and paths of spread, interior spatial configuration, and victim location. In firefighting jargon, this is called the "size-up." This information gathering process happens very quickly and is largely dictated by time-pressure, acute stress, memories of previous experience, and what one has been taught to look for.

From the Inside – Based on the assigned task, the interior configuration of a burning building shapes how firefighters will move through it. Engine company firefighters are concerned primarily with the paths of circulation between compartments (rooms) because it is their job to move a charged handline through the building to extinguish the fire. The ladder company firefighters travel the same circulation corridors but also search each compartment. It is their job to search for the fire and for victims. The ladder company firefighters often perform this work without the aid of a hoseline, working from the seat of fire back to the entry. They orient primarily to the patterns of the interior spatial configuration – to the walls, doors, windows, furniture, and flooring.

From the Topside – In certain circumstances, ladder company firefighters will work from the roof of a structure. Their job is to create holes in the roof assembly to exhaust superheated gases and toxic smoke; this is called vertical ventilation. When these firefighters operate topside (on the roof), they make educated guesses and predictions about the interior spatial configuration (floor plan) below. These firefighters regularly operate above the fire, and as a result, they must always be cognizant of the condition of the construction assemblies beneath their feet and aware of the configuration of rooms below.

The sequence *outside, inside, then topside* integrates spatial, environmental, and fire/smoke behavior patterns of cues into (relatively neat) categories that limit the possible number of situations to which a firefighter may respond to. Grouping information this way reduces perceptual chaos and works to structure wayfinding practices. Firefighters benefit from the fact that they operate within "a series of interlocking routines, habituated motor programs that bring the same people together around the same activities in the same time and places."[67] What they lack, however, is a shared frame of reference. This thesis proposes that the floor plan is useful common ground between firefighting tasks and positions. It is the shared frame of reference firefighters know exists but may not be able to articulate. One is always, to some degree or another, aware that patterns exist. We all have some experience with the types of houses and patterns of cues associated with them. This experience (some might say that it is a form of expertise) is not leveraged in any existing training model in the modern fire service.

It can be said that each firefighting unit requires an individual thinking disposition (which includes orientation, navigational strategy, operational tempo, and internal clock) and uses environmental information differently, sometimes very differently. While the fireground may largely be a place of structured response, or ritual, a firefighter's environmental (spatial and fire behavior) expectations must not be held too rigidly. Firefighters encounter unique circumstances in every fire. These include unexpected building and spatial configurations due to un-permitted renovations, odd do-it-yourself interior modifications, hoarding conditions, interior grow or drug-lab operations, and situations that make sense only after the incident is completed. Wayfinding in smoke requires *flexible seeking-out-routines* and *thinking dispositions* that allow information to be obtained directly from the environment – critical information that may prove lifesaving. Firefighters need simple, open-ended wayfinding practices that accommodate uncertainty. The goal is to reduce cognitive demand and increase attentional capacity and situational awareness.

3.9 A Useful Phenomenology of Orientation

Houses are composed of distinct interior configurations. Even in smoke, one experiences these spatial configurations as organized networks of interconnected places. Thus, one can learn to recognize and interpret them quickly. As Ruth Conroy Dalton explains, "any set of spaces, of sufficient complexity to be described as a configuration, tends to form a spatial hierarchy in which some spaces become more strategic and others less so."[68] Buildings can be conceived as geometric forms (shapes) with certain combinations of rooms that are more probable than others. Houses can be simplified into *paths* (circulation corridors) and *places* (compartments, or rooms). In almost all houses, regardless of type, the paths between interior places create encounters with repeatable angles and intersections — *90 degree turns* (left/right), *Tee* (intersection where one can only go left or right), and *180 degree turns*.[69] (The number of houses organized on triangular or hexagonal modules, as in certain works by Frank Lloyd Wright, is minuscule in comparison to those with 90-degree corners and rectangular or square rooms). Conceived this way, the problem of navigating and staying oriented in smoke becomes less daunting.

Firefighters require *survey (allocentric) knowledge*, which is defined as knowledge of the respective locations of paths and places relative to each other. They also require *route (egocentric) knowledge*, which is the kind of knowledge about specific stimuli that should be perceived along a route, in a serial fashion, rather than abstractly.

Humans experience spaces as organized networks of interconnected places. This is essentially why one can identify why something is in the wrong place and why one can successfully navigate one's own home blindfolded; one has come to unconsciously "know" these spatial configurations. The standard organization of rooms and one's familiarity with them facilitate visually-impaired navigation. Firefighters benefit from familiarity (derived from past experience in houses with similar configurations) when they need to navigate in smoke. Studies have shown that the geometry of the environment strongly influences "how we retrieve spatial information about that environment."[70] Prior knowledge and experience in such networks (of paths and places) shapes and directs expectations and perceptions.

Abstracting houses into shapes, types of configurations, and patterns of cues can help guide the mind where to find the information it needs to make "educated guesses" about the environment. Firefighters depend heavily on wayfinding techniques adapted to navigation without sight. In addition, firefighters use feel to identify flooring, furniture, and room types, among other things. Heat energy, felt through protective equipment, is used to direct the firefighter toward the fire. Firefighters consistently work from their knees, crawling in a head-down/up orientation and must have good body awareness in an environment where landmarks are distorted by the smoke. In the absence of visual cues, firefighters rely more on somatosensory, vestibular, auditory, and proprioceptive modes of apprehension, which are less practiced, not well-understood, and generally slower. To navigate effectively, the environment must be schematized into paths and places relative to a frame of reference; a representation that allows the quick integration of sensory fragments into useful wholes.

An established geometric frame of reference can break down complexity inherent in the residential built environment into simple chunks of spatial information that can be used to sequence behavior. The fireground rituals are a method of anchoring and transmitting experience in the minds of firefighters who take part in the action. The known shapes, patterns, and configurations of residential houses, inside and outside, can better inform the seeking-out-routines firefighters use.[71] Knowing these patterns can improve firefighters' "size-up" practices.

The relative standardization of residential design in the United States has been the result of craft practice, experimentation, empirical knowledge, and a process of industrial optimization. Standard patterns of single-family residences provide flexible templates for wayfinding in smoke. Firefighting "rules" are generally well-established. For example, put water directly on what is burning or locate the fire and search back from there. The recognition of the repetitive character of single-family houses, and its "rules" and "patterns (of cues)" can form an essential context for orientation and navigation in the house when it is on fire and filled with smoke. This is largely ignored in firefighter training, manuscripts, and research. The regularity of the single-family house supports *rule-based* and *pattern-based decision-making*, algorithms and heuristics – and *improvisation*, when necessary.

Template theory, which is commonly cited in decision-making and jazz music research, involves a "core, which is the non-variable part of the template, and slots, which constitute the variable part."[72] All dwellings, especially single-family houses, can be thought of similarly in that they too have non-variable and variable parts. For example, at minimum, houses today have five standard rooms: the *living room*, *dining room*, *kitchen*, *bedroom*, and a *bathroom*. These are the non-variable rooms of the house. The variable parts can be any number of things (for example, additional bedrooms and bathrooms, an office, and so forth). Without a framework in place to support assessment, decision-making, and wayfinding practice, firefighters can and do come dangerously close to disorientation.

The complicated or unexpected spatial configurations found in real buildings can make this situation even worse, because they require firefighters to question learned spatial patterns and to store more spatial cues in already over-taxed short-term (working) memory; this can lead to distortions and compounding navigational errors. Typical firefighter education can exacerbate this problem because firefighters are usually conditioned in highly standardized and sterile training environments. Consequently, they tend to apply habitual wayfinding tactics to novel spatial configurations, or they overcompensate with poorly informed navigational decisions in the moment, sometimes with grave consequences.

3.10 Conclusion

Firefighters seldom ply their trade in the same place. Given that firefighting is to a certain extent, "an 'ad hoc' profession," firefighters require a flexible perceptual and cognitive toolbox, organized spatial knowledge, and portable solutions to problems. [73]Firefighters are bombarded with too much information and at the same time must make decisions on too little information.[74] In the book *Shop Class as Soulcraft: An Inquiry into the Value of Work,* Matthew B. Crawford writes

> Knowing what *kind* of problem you have on hand means knowing what features of the situation can be ignored. Even the boundaries of what counts as 'the situation' can be ambiguous; making discriminations of pertinence cannot be achieved by the application of rules, and requires the kind of judgment that comes with experience.[75]

In firefighting practice there is never enough time to gather enough information to make a perfect decision. Firefighters must make quick, "good-enough" judgments, and decisions.[76] The reality of the environment of a fire is that wayfinding problems do not present themselves clearly in many cases. It is difficult to know what is pertinent and what is not. A firefighter's ability to make good judgments "is holistic in character and arises from repeated confrontations" with fires in structures like houses.[77] It is possible to think of firefighting actions as "formed by gestalts or chunks, triggered by the setting's schema. By forming categories or similar examples of appropriate responses to a situation, actions are improved and the appropriate response to a situation can be done without considering each new situation in all its detail."[78] Wayfinding requires that firefighters recognize their position and destination and plan an efficient route between these locations. Furthermore, one's position on the route needs to be monitored. One's level of arousal and their physiological response to stressors can make wayfinding difficult. Kenneth Hill states that some activities, like firefighting, "put a person at risk for getting disoriented, because they can require a concentration of mental resources on the activity to the detriment of monitoring direction."[79] Without a basic understanding of typical floor plans (and associated variables), wayfinding in smoke is made more dangerous because decisions about the environment are basically left up to chance.

Firefighters' actions on the fireground reflect generalized routines. No situation a firefighter encounters ever replicates another exactly, but a firefighters fall back on habits formed in training and through first-hand experience. Therefore, firefighting is, surprisingly ritualistic. Firefighters enact variations of these routines on the basis of a quick appraisal of the situation, and then make further adjustments as they advance toward the fire. In its current form, firefighting training builds routines that form an initial set of elemental wayfinding tools. But the training usually stops there. Firefighters, need other means of coordinating their movements in smoke and orienting to stable features of the built environment (i.e., the floor plan).

Firefighters' skills, "are not unlike those of the scientist; one learns through direct experience and the testing of hypotheses," relying on information drawn from multiple knowledge domains.[80] It is one thing to study theory or know what to look for, these clues and signs and indications; it is quite another to pull it all together and confront in the moment the ever-changing reality of the fire, while surrounded by dark, toxic smoke.[81] The next chapter, Chapter 4, examines the brain processes that are thought to lie behind the human ability to wayfind. This information is placed within the context of firefighters who are tasked with finding their way in dark smoke to rescue those trapped or incapacitated – *as fast as possible*.

Image 3.8 Firefighters about to make entry. Sheri Hemrick photo.

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Image 4.1 Firefighters come to know the built environment through up-close interaction with fire. Sheri Hemrick photo.

CHAPTER FOUR

Understanding What Firefighters "Know"

"Our brains create much of what we see by adding what 'ought' to be there. We only realize that the brain is guessing when it guesses wrongly, to create a clear fiction."[1]

– Eric R. Kandel

4.1 Introduction

Chapter 4 relates current brain science literature to the firefighting practice of wayfinding in smoke. This chapter begins with a fictitious example of the firefighting sequence. It is, however, a realistic representation of how firefighters respond to a fire, from the initial dispatch until firefighters step inside the smoke. The sequence is followed by a translation of the coded language firefighters use. The goal of this chapter is to convey basic information about the structure of the human visual system, memory processes, and the brain's spatial mental models.

The brain is a simple-looking mass of tissue whose shape and structure do little to explain how it functions or why it is important to the human organism. However, modern imaging technology has made the anatomical structure of the brain and its biological, chemical, and electrical processes visible and comprehensible. Brain science researchers typically describe "basic brain function with a triumvirate approach" – neuroelectricity, neurochemistry, and neuroanatomy.[2] This approach identifies the two ways the brain communicates – through electrical impulses and chemical exchanges – and where this communication takes place. The brain's hardwiring shapes one's understanding of any environment to an extent only now being understood. The nervous system can be described as a "continuous loop of communication between brain, spinal cord, and body."[3] And the language of the nervous system are patterns of electrical and chemical signals that travel through neural circuits.

The body's sensory systems feed the brain a steady diet of information that it uses to make decisions and predictions as a person moves through an environment. Psychologist Barbara Tversky writes, "on the neurological level, neurons fire or don't. On the cognitive level, the continuous input is so rich and complex that much of it must be, and is, ignored; the input must be categorized to be effectively processed and understood."[4] We perceive only a small amount of the stimuli that enters the brain. The brain relies on multiple different sensory systems – visual, somatosensory, vestibular, auditory, proprioceptive, and memory, among others, to make sense of the environment. The brain takes incomplete information about the outside world received from one's senses and "makes it complete."[5] Neuroscientist Eric R. Kandel writes in *The Age of Insight: The Quest to Understand the Unconscious in Art, Mind, and Brain,* that "a guiding principle in the organization of the brain is that each mental process – perceptual, emotional, or motor – relies on distinct groups of specialized neural circuits located in an orderly, hierarchical arrangement in specific regions of the brain. This is also true of the visual system."[6] The nervous system, of which the brain is a critical part, is creative in how it gathers, interprets, stores, and uses sensory information. Kandel writes

> The models that our brain constructs about the world animate our visual attention on a moment-by-moment basis. Thus, we live in two worlds at once, and our ongoing visual experience is a dialogue between the two: the outside world that enters through the fovea and is elaborated in a bottom-up manner, and the internal world of the brain's perceptual, cognitive, and emotional models that influences information from the fovea in a top-down manner.[7]

In the case of firefighters, the brain rapidly sorts through a constant and confusing flow of multi-modal sensory information and turns the circumstances of the situation into a model that can be comprehended explicitly and serves as a springboard for firefighters' actions on the fireground. Firefighters' "size-up" includes assessing features of the building, the extent of smoke and fire propagation, and includes making determinations as to the best course of action. For example, the first-arriving engine company tries to identify *what* is burning, *where* the fire is going, and *how* to get there to extinguish it. The first-arriving ladder company tries to identify *how many* people are trapped, *where* they might be located, and *how* to access them. Assessments such as these set in motion a cascade of actions to suppress the fire and rescue trapped or incapacitated civilians. It makes sense then, for firefighters to be taught how the brain's perceptual, cognitive, and memory processes work together to facilitate wayfinding in smoke while simultaneously managing time-pressure and acute stress, in this high stakes, uncertain environment.

The chapter is organized into four parts. Part 1 briefly examines the NFPA's national response time standards to illustrate how quickly the firefighting sequence is enacted. Part 2 describes how the human visual system functions. Firefighters make rapid visual assessments and interpretations of the environment (for example, of patterns of cues related to the house and fire/smoke conditions). This section is concerned with understanding how the visual system extracts information needed for wayfinding tasks such as fire suppression and search/rescue from environment. Part 3 relates human memory processes to firefighting practice. In a time-sensitive emergency situation, firefighters do not have time to compare multiple options before deciding on a course of action. Wayfinding relies heavily on memory, but human memory limitations are exposed in acute stress and in emergency situations. Part 4 discusses the architecture of the brain's spatial mental models. This chapter summarizes the essential concepts of the perceptual and cognitive processes that are thought to lie behind the human ability to successfully wayfind.

PART 1 – THE FIREFIGHTING SEQUENCE

4.2 Firefighting Performance Benchmarks

Two minimum time standards established by the NFPA are useful to emphasize and describe the time-sensitive nature of the firefighting response to a reported fire. *NFPA 1221: Standard for the Installation, Maintenance and Use of Emergency Services Communications Systems* and *NFPA 1710: Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments* establish performance benchmarks that fire departments use to measure their responses. The following time standards are taken directly from the NFPA 1221 and 1710 documents on-line.[8]

- **Alarm Answering Time** – The dispatch center must answer the 911 call within 15 seconds for 95% of calls; 40 seconds for 99% of calls.
- **Alarm Processing Time** – The dispatcher must process the alarm within 64 seconds for 90% of calls; 106 seconds for 95% of calls.

- **Turnout Time** – Upon receipt of the alarm, firefighters must respond within 60 seconds for EMS responses; 80 seconds for fire responses.

- **First Engine Arrive on Scene Time** – The first fire suppression apparatus must arrive on scene within 240 sec (4 minutes) for 90% of responses with a minimum staffing of 4 personnel.

- **Second Company Arrive on Scene Time** – Following the arrival of the first-due unit, the second company must arrive within 360 seconds (6 minutes) for 90% of responses with a minimum staffing of 4 personnel.

- **Initial Full Response** – The entire alarm must arrive at Low and Medium Hazard Assembly occupancies within 480 seconds (8 minutes) on 90% of responses.

- **Initial Full Response** – For High Hazard/High-Rise Assembly occupancies, the entire full response must arrive within 610 seconds (10 minutes 10 seconds) on 90% of responses.

The longer the fire burns, the worse the situation becomes; the more dangerous it is for everyone – civilians and firefighters alike. Survival rates for civilians trapped inside a house drop precipitously with each minute the fire is allowed to burn freely. According to the Society for Fire Protection Engineers' *(SFPE) Guide to Human Behavior in Fire*,

> Once a victim has become trapped or incapacitated in a fire, conditions can become lethal within a few seconds to minutes; unsuppressed flaming fires can grow exponentially as does the heat smoke, and toxic gases produced by these types of fires. The key determinant of survival in a fire is the time to incapacitation. Incapacitation occurs when the occupant is no longer capable of self-preservation due to exposure to toxicants, irritants, and heat in a fire.[9]

The single most-effective action firefighters can do to positively affect the situation and save lives is to make rapid, accurate visual assessments before they step into the smoke. This assessment allows them to know where to direct their efforts to effect rescues and suppress the fire. There is no time to waste. The public expect firefighters to know exactly where to go to find them.

The following is a fictitious example of radio transcripts that illustrates how the firefighting sequence is enacted and information is conveyed to responding firefighters – from the initial 911 call to the point firefighters step into the smoke. While the example takes place in Seattle, Washington, it represents a standard sequence that occurs every day throughout the United States:

<u>0:00 – The 911 call:</u>

(Call-taker) 911 what is your emergency? *(Caller)* Help! Oh my God! The house next door is on fire. My neighbor is screaming that her son is still inside. Please hurry! [*Inaudible screaming heard in the background]* Hurry! The whole side of the house looks like it is on fire! [*The caller hangs up]*

<u>1:04 – Initial dispatch:</u>

(Dispatcher) Engines 6, 30, 13, 25, and 34; Ladders 3, 10, and 1; Battalions 5 and 2; Medic 10; Rescue 1; Safety 2, Staff 10, Air 10, Deputy 1 respond to 314 26th Avenue for the house on fire. We have received multiple calls. People reported trapped. Unable to get more information, the caller hung up. We are attempting a call-back now.

<u>4:50 – Initial arrival report:</u>

(First arriving engine officer) Dispatch from Engine 6. Engine 6 is at 314 26th Avenue. Working fire. Engine 6 will establish 26 Avenue command. We are on a hydrant. Single-family SOG in effect. Standby for a 360 report….

<u>6:46 – 360 Survey:</u>

(First arriving engine officer) All units from 26 Avenue command. 360 complete. We have a fire showing from two windows on the delta side, floor one of a one-and-a-half story, wood-frame house. Heavy smoke from floor 2 and the roof. The structure has a basement. No smoke or fire visible in basement. Engine 6 will be stretching a preconnect through the front door…. [Break] All units from 26 Avenue command, we have a confirmed report of a child trapped in a floor two bedroom. Child is approximately 10 years-old…. [Break] Ladder 3, on your arrival search floor 2…. [Break] Second due truck, check for extension above. It appears that we have fire in the knee walls….We may need to open the roof. [Break] Dispatch from 26 Avenue command, add a medic response for confirmed victim…. [Break] On your arrival Engine 30, I will look to transfer command. I'll assume fire attack.

Translation

Firefighters are notified to respond to the fire by a combination of tones, bells, and lights throughout the station. Upon hearing the alarm, firefighters report to their assigned apparatus' riding position, quickly dress into their bunking gear, and respond (or "turnout" in firefighting jargon) to the fire. NFPA standard turnout time is 80 seconds. This means that from the furthest point in the station from the apparatus bay (or from sleep), firefighters have 80 seconds to dress in their protective equipment and respond. Once they have dressed into their protective equipment, a fire suppression is expected to arrive within 4-6 minutes of the dispatch in areas with full-time fire protection. Nationwide, response times vary widely.

Engine 6 begins the fire suppression and search sequence by notifying the Fire Alarm Center (i.e., the dispatch center) that the first fire company has arrived on scene and has confirmed the correct address. The officer in charge then confirms that this is a working fire. This alerts incoming units that they will be immediately put to work based on the applicable SFD Standard Operating Guides (SOGs). Engine 6 reports that they are 'on a hydrant' which means that the first-arriving engine parked within 100′ of a hydrant. It is standard practice in Seattle (and nationwide, to an extent) to begin a fire attack on tank water, then establish a positive water supply.

The Engine 6 company officer must look at all sides of the structure to confirm the fire location before sending firefighters inside. From the initial radio traffic, the company officer reports that fire has vented out two windows, which could mean the fire has spread to multiple rooms. This officer has assigned the two firefighters to stretch a pre-connected 1.75″ hoseline to the front door and inside. Based on the officer's quick lap around the structure (which is often limited by fences, cars, topography, size of building, and proximity of other buildings), it was determined that the front door provides the best access to the fire. This fire quickly becomes more serious and chaotic as the officer is met in the front yard by the child's hysterical mother who confirms that her young child is trapped upstairs in the bedroom. The company officer must quickly gather and convey critical information (location, age, and best route of travel to victims last known location) to incoming units. Then, the officer requests additional medical resources to attend to the child once he or she is removed from the structure.

Firefighters name the sides of the building in a clockwise fashion – alpha, bravo, charlie, delta (or in some states – 1, 2, 3, and 4). Smoke from the eaves is an indication that fire may be burning in the void spaces surrounding the upstairs compartment. As a result, the Engine 6 officer communicates the need to check for extension. Lastly, in many fire departments, the firefighters deepest inside the buildings are the newest ones. The Engine 6 officer asks to transfer command of the fire to the next-arriving officer on Engine 30. This decision is made in order to supervise the two firefighters who have stretched their hoseline to the front door and are about to step into the smoke to locate and attack the fire.

On their arrival, two members from Ladder 3 make entry into the house before the engine firefighters enter the front door to rapidly locate the stairs up to the second floor in order to search for and remove the trapped child. The two other members from Ladder 3 will begin throwing ladders to windows on floor 2. If possible, they will enter floor 2 to perform a window-based search which facilitates rapid access to the upstairs rooms.

This "story" is articulated and made sense of by firefighters, many of whom are not on scene yet, in a matter of minutes. For example, while responding, firefighters "use this time (typically between 4 and 7 min.) to draw upon whatever prior knowledge of the incident site is available and discuss the likely nature of the emergency situation."[10] Firefighters actively simulate "what the situation might be and consequent appropriate actions in the light of available prior knowledge."[11] Researchers Jim McLennan and Mary M. Omodei, in "The Role of Pre-Priming in Recognition-Primed Decision-Making," write that upon arrival,

> The officer inspects the situation and compares the visual evidence available with his enroute simulations of the likely situation, i.e., the pre-primed prototypes. If the evidence is recognized as being consistent with one of his simulated simulations, this scenario becomes the basis for subsequent decision-making action with those action alternatives embodied in the pre-primed prototype being considered first. On the other hand, if the evidence is inconsistent with all of his simulations, he reassesses his characterization of the situation and examines a new sequence of possible actions.[12]

Descriptions from firefighters on scene connect past experience, present conditions, and future actions in mind. Firefighting, to an extent is performed and made sense of through "stories;" all made possible by the brain. Thus, sensemaking in the context of firefighting practice can be described as the "experience of being thrown into an ongoing, unknowable, unpredictable streaming of experience in search of answers to the question, **'what's the story?'**"[13]

Disclaimer: *This chapter examines brain science literature from an appropriate academic distance, and with the full acknowledgment that these subjects require extensive medical and scientific training, neither of which the author has. Expert research is extensively cited, along with contextual statements by this author, to help the reader remain oriented to the scope and relevance of brain science research to this thesis. The following chapter includes summaries of detailed brain science literature. As with any summary, there is the chance that the descriptions underestimate and do not fully convey the complexity of the brain processes. However, every effort has been made to maintain accuracy.*

4.3 Making Rapid "Educated Guesses"

Neuroscientist Eric R. Kandel writes that "the visual brain is a pattern-recognition device. It specializes in extracting meaningful patterns from the input it receives, even when the input is extremely noisy."[14] The brain needs a stable point of departure for its inferences — its search for patterns. Fire and smoke conditions constantly change, so the brain needs something stable on which to base its hypotheses. The house itself is very often the most stable object in the fire environment.

Psychologist Barbara Tversky writes that "mind organizes information into recognizable and informative packets. We use these packets (units) of information for understanding, and prediction."[15] The "mind," as defined in brain science literature, refers to the set of operations carried out by the brain. These operations generalize, categorize, and reconstitute information; provide context, and resolve ambiguity. The mind tolerates ambiguity by organizing information in specific ways and by creating and testing a number of "working hypotheses," or "educated guesses." The primary purpose of the mind's predictions is to learn about the environment.

The mind creates and uses "educated guesses" extensively.[16] For example, Steven Kotler, author of *The Rise of Superman: Decoding the Science of Ultimate Human Performance*, analyzed the brain science research from the perspective of professional adventure athletes (for example, backcountry skiers, base jumpers, and big-wave surfers, and so forth) who have consistently pushed the boundaries of human performance.[17] Given the speed at which things happen in these environments, the brain's ability to predict the future has proven to be one of the key determinators in staying alive. The brain has a highly developed pattern-recognition system. Writing about the mind's predictive capability, Kotler says,

> So important is prediction to survival, that when the brain guesses correctly — i.e., when the brain's pattern-recognition system identifies a correct pattern — we get a reward, a tiny squirt of the feel-good neurochemical dopamine. Dopamine feels really good. Cocaine, widely considered one of the most addictive substances on earth, does little besides cause the brain to release dopamine and then block its reuptake. This same rush reinforces pattern recognition — its why learning happens. But dopamine actually does double duty. Not only does this neurotransmitter help us learn new patterns, it also amps up attention and reduces noise in neural networks, making it easier for us to notice more patterns. And noticing patterns actually prepares the brain to notice more patterns. It is why creative insights tend to snowball. Once we do the hard work of identifying that first pattern, the dopamine dumped in our system primes us to pick out the next. And the next. Neurons that fire together wire together. The more times a particular pattern fires, the stronger the connection between neurons becomes, and the faster information flows along this route.[18]

When operating at the limits of human performance, one's mind tries to "predict the future," and dopamine acts as a "teaching signal."[19] One way the mind accomplishes this is through pattern-recognition. The same pattern-recognition system that helps adventure athletes stay alive can help firefighters recognize patterns in built environment. This system is active in each of us – *all the time*.

Firefighters engage in a form of "holistic or global processing of overall patterns" of the houses they encounter.[20] The mind encodes "visual features as larger perceptual units" which gives one "the ability to rapidly encode a 'gestalt' of a scene which allows the extraction of a rapid understanding of the scene using global or statistical information."[21] Gestalt theory is a contributing factor in the mind's ability to recognize and rapidly interpret patterns of house types. Gestalt theory is a set of descriptive organizational principles describing how one perceives the form of an object. Gestalt theory categorizes and describes the various ways the brain perceives visual elements as unified wholes, thus meaningful information. The theory illustrates how the mind prefers things that are simple, clear, and orderly, because they take less time to process. The brain is always looking for ways to increase efficiency. Over time, certain patterns (be it visual, tactile, environmental, or motor) and types of information are written into the brain's circuitry and no longer consciously accessible – they become hardwired, automatic. Others can be accessed consciously. When confronted with complex configurations or shapes, as often found in the built environment, the mind tends to reorganize them "into simpler components or into a simpler whole."[22] Kandel, in his study of the relationship between the brain and impressionist and abstract art, points out the influence of Gestalt psychologists on the understanding of the visual system. He writes, "Gestalt psychologists brought two radically new concepts to bear on visual perception. They insisted that the whole is more than the sum of its parts and that our ability to grasp those relationships – to evaluate sensory information holistically and assign it meaning – is largely inborn."[23] Kandel writes further,

> The German word Gestalt means configuration, or form. Gestalt psychologists use it to refer to the fact that in perceiving an object, a scene, a person, or a face, we respond to the whole rather than to the individual parts. We do this because the parts affect one another in such a way that the whole ends up being much more meaningful than the sum of its parts.[24]

The mind, according to Gestalt principles, seeks to group parts as some whole. Using Kandel's logic, houses are composed of a standard set of rooms grouped together into recognizable configurations – illustrated in the catalog of house types in the next chapter. The relationship between the interior spatial organization and exterior shape and patterns of cues that serves as a Gestalt valuable to firefighters.

4.4 A Brief Introduction to the Human Visual System

Humans are sensitive to a variety of stimuli, such as light, sound, heat, pressure, orientation, and locomotion, (i.e., movement). In general, all sensory information is translated into electrical or chemical signals, or "neural codes: that is, patterns of action potentials generated by nerve cells" sent through neural networks to the brain.[25] These electrical or chemical codes are the language of nervous system. The nerve cell, called the neuron, "is the fundamental building block and signaling unit of all nervous systems."[26] Of concern to this section is how external information about the built environment is translated (or transduced, the term used in brain science literature) into neural activity and into the image we "see."[27] The section examines how one type of information (for example, reflected light) is changed into a different type of information (for example, a neural signal) and what that means for firefighters assessing the house on fire.[28]

The visual system can be thought of in the following way: "our eyes provide information about the environment around us in a rather imperfect mix of visual signals that must be interpreted by the brain before any meaningful perception can occur. The brain sorts these signals according to which information is most vital for understanding risks in the surrounding environment."[29] The human brain works hard to separate out the useful information from the "noisy" background. For example, visual information begins as reflected light and is translated into patterns of electrical signals. The resulting retinal image is essentially a pattern of light. Kandel explains how the visual system creates,

> …Representations in the brain (in the form of neural codes) that require far, far more information than the modest amount the brain receives from the eyes. That additional information is created within the brain. Thus, what we see in 'the mind's eye' goes dramatically beyond what is present in the image cast on the retina of our real eye. The image on the retina is first deconstructed into electrical signals that describe lines and contours and thus create a boundary around a face or an object. As these signals move through the brain, they are recorded and, based on Gestalt rules and prior experience, reconstructed, and elaborated into the image we perceive.[30]

The brain science literature makes a distinction between two terms – *sensation* and *perception*. These two terms appear regularly in the reviewed literature (and in subsequent pages). *Sensation* is the immediate biological consequence of stimulating a sensory organ, such as the photoreceptors in our eyes or pressure sensors in the fingers.[31] *Perception* incorporates the information our brain receives from the external world with knowledge based on learning from earlier experiences and hypothesis testing.[32] Put another way, sensation is the process by which one receives information from the environment and perception is the "interpretation of information from the environment" so that one can identify its meaning.[33] Perception can be reflexive or deliberate.

Brain science researchers, including Kandel, report that "fully half of the sensory information going into the brain is visual."[34] In order to construct a coherent representation of the environment, one's eyes are constantly in motion. The rapid movement of the eyes – between fixation periods – are called *saccades*. The eyes scan so "quickly that we seem to see a whole image at once, but it is only during the fixation period between saccades that we consciously take in what we see."[35] These saccades, have a twofold purpose: "They enable the fovea to explore the visual environment, and they make vision *per se* possible (if our eyes focus on one spot for any significant period of time, the image will start to fade)."[36] Kandel writes, "but it is the brain that determines where the eyes will move – and the brain makes these decisions by testing hypotheses about the nature of an image."[37] Writing about physician and noted physicist Herman von Helmholtz's study of vision, Kandel explains

> To reconstruct the dynamic, three-dimensional world from which the image was formed, the brain needs additional information. In fact, if the brain relied solely on the information it receives from the eyes, vision would be impossible. He therefore concluded that perception must also be based on a process of guessing and hypothesis testing in the brain, based on past experiences. Such educated guessing allows us to infer on the basis of past experience what an image represents. Since we are not normally aware of constructing visual hypothesis and drawing conclusions from them, Helmholtz called this top-down process of hypothesis testing *unconscious inference*. Thus, before we perceive an object, our brain has to infer what the object might be, based on information from the senses.[38]

In 1967, Russian psychophysicist Alfred Yarbus performed a series of experiments that studied subjects' eye movements as they examined works of art. According to Kandel, "he found that the time allocated to a feature is proportional to the information contained in it" and one's *purpose* for looking.[39] As discussed earlier, firefighters asses the house on fire from three related, but different frames of reference (engine company, ladder company, and incident command). Yarbus' eye movement experiment and a follow-up study by C.F. Nodine and Paul Locher discovered that there are three "stages in visual perception and that these stages are evident in the scanning eye movements used in examining a work of art."[40] Because no eye movement studies have been performed on firefighters, one must extend from their research and posit that firefighters' eyes scan the building and fire scene similarly. Their eyes scan the fire building first in a global, or holistic manner seeking to identify the stable features (i.e., people, places, and objects), and then rapidly integrate

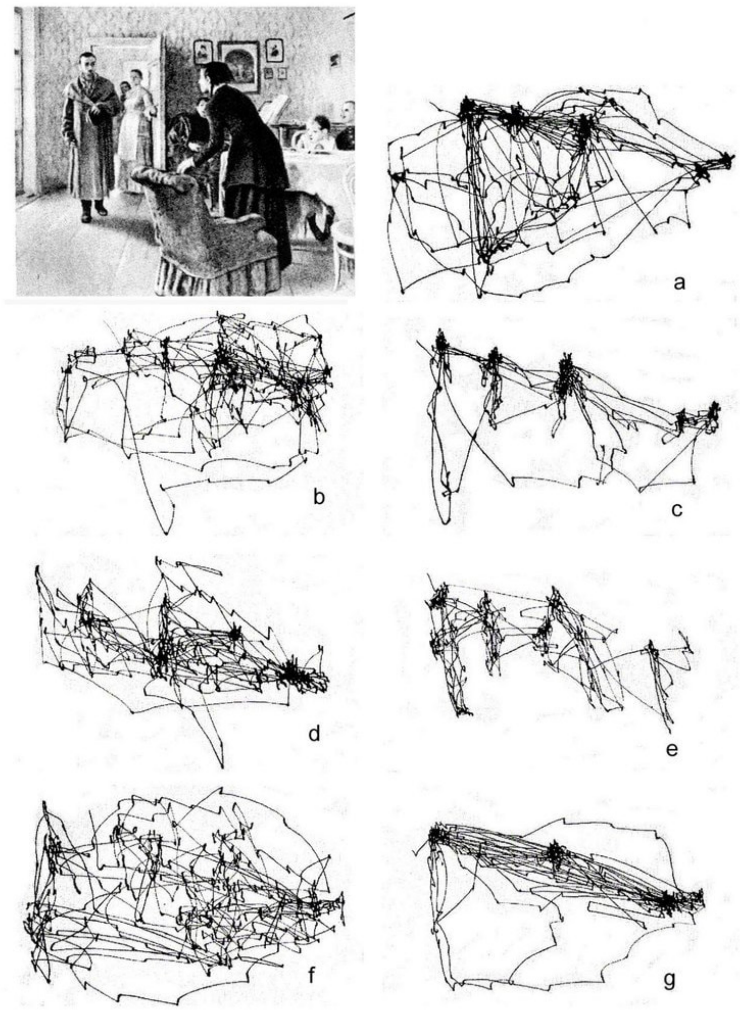

Figure 4.2 Records of one subject's eye movement, from Alfred Yarbus' influential eye movement study.[188]

this information with one's own personal experience producing an emotional and motor response to the situation.[41] Published in "Eye Movement and Vision" (Figure 4.1) Yarbus writes,[42]

- (A) Free examination of the picture.
- (B) Estimate the material circumstances of the family in the picture.
- (C) Give the ages of the people.
- (D) Surmise what the family had been doing before the arrival of the 'unexpected visitor.
- (E) Remember the clothes worn by the people.
- (F) Remember the position of the people and objects in the room.
- (G) Estimate how long the 'unexpected visitor' had been away from the family.

Yarbus showed that there is a tendency to make repeated cycles of fixations (the brain science term for maintaining a gaze at a single location) between key features of the object being viewed. This is especially true for eyes and faces. The purpose of the fixation is to focus the fovea on something to allow it to take in detailed information. It seems reasonable that firefighters' eyes scanning the house on fire perform in a similar manner, but do so while the firefighter is moving *and* the visual scene is constantly changing because of the fire and smoke. It is not hard to imagine how easy it is for the one's eyes to miss important information.

One's rapid eye movement, purpose for looking, and the sensory overload firefighters commonly experience on the fireground results in two types of failure of visual awareness – *inattentional blindness* and *change blindness*. In both cases, one fails to "see" something right in front of one's eyes. In "Change Blindness and Inattentional Blindness" psychology graduate student Melinda Jensen writes, "Inattentional blindness is defined as a failure to notice an unexpected, but fully visible item when attention is diverted to other aspects of a display due to one's narrowed scope of vision. Change blindness is the surprising failure to detect a substantial visual change."[43] The anatomy of the eye itself also contributes to failures in visual awareness as described by Kandel,

> The densely packed cones in the fovea pick up the fine details of an image but do not perceive well the coarser, large-scale components of an image, whereas the more widely spaced rods in the periphery of the retina do. Thus, the brain processes visual information in two ways: on a fine scale, for a parts-based analysis, and on coarse scale, for a holistic analysis.[44]

Thus, the brain fills "in around incomplete information" with what one most expects. This "is the basis of countless visual tricks and illusions. It is the foundation of magic" and it is often the root of visual failures on the fireground.[45] These failures expose the mismatch between what one thinks they see and what one *actually* sees.

4.5 The Inverse Optics Problem

Vision is analogical in nature. Meaning, one perceives an object by constructing a spatial analogy of it, which one comes to believe to be the objects itself. This is the result of the projection of a three-dimensional world onto a two-dimensional retina. It is not possible for a two-dimensional image on the retina to exactly replicate the three dimensions of an object.[46] From this point of view, visual perception will always seem problematic. The literature refers to this issue as the "inverse optics problem." The problem concerns how the brain takes the incomplete information about the outside world that it receives from the eyes (and other senses) and makes it complete. Kandel puts the problem very simply: "Any image projected onto the retina of the eye has countless possible interpretations."[47] One's recognition and interpretation of visual information from the environment depends entirely on one's cognitive toolkit – the "beholder's share" according to Kandel. Kandel writes, "the meaning of an image depends on each viewer's associations, knowledge of the world…and ability to recall that knowledge and bring it to bear on the particular image."[48]

The beholder's share presents a two-part problem associated with wayfinding in smoke. First, firefighters need to recognize, interpret, and convey spatial information consistently, but every human brain takes incomplete visual information *(bottom-up)* and makes it complete in their own unique way *(top-down)*.[49] Second, the neuro-chemical state induced by stressors associated with firefighting is highly individual and situationally dependent, so the ways in which individual firefighters bring the "beholder's share" to bear on the situation may vary widely. Insights into the biology and the cognitive psychology of perception and emotion are helpful to understand how firefighters make sense of emergency situations and wayfind in smoke.

4.6 Solving the Inverse Optics Problem

According to Kandel "the mammalian eye is not a camera; it does not record the image of a scene or a person pixel by pixel, nor does it capture accurately the colors of the image. Moreover, the visual system can pick and choose and discard information, which neither a camera nor a computer can."[50] What one sees is actually a construct that is built up over time, from experience. The mind then assigns meaning to the images. German physicist Herman von Helmholtz argued that solving the inverse optical paradox requires the brain to use two additional sources of information: *bottom-up information* and *top-down information*.

According to Kandel, ***bottom-up information*** is "supplied by the computations that are inherent in the circuitry of our brain. These computations are governed by universal rules that are largely built into the brain at birth by biological evolution and enable us to extract key elements of images in the physical world, such as contours, intersections, and the crossing of lines and junctions."[51] Bottom-up processing is "data driven processing; it is based on sensory experience."[52]

Kandel writes that, ***top-down information*** **"**refers to cognitive influences and higher-order mental functions such as attention, imagery, expectations, and learned visual associations. Because bottom-up processing cannot resolve all of the perplexing information we receive from our senses, the brain must engage top-down processing to resolve the remaining ambiguities. We must guess, based on experience, the meaning of the image in front of us. Our brain does this by testing a hypothesis. Top-down information places the image into a personal psychological context, thereby conveying different meanings about it to different people."[53] Top-down processing, is "memory driven."[54]

The hypotheses constructed by the mind are created in part on "built-in knowledge – knowledge that we inherited through natural selection and that is stored in the wiring of the brain's visual system."[55] And in part by "comparing it with previously experienced and remembered images" – from memory.[56] What all this point to is "that what we see – our interpretation of any element in an image – depends not just on the properties of that element, but also on its interaction with other elements in the image and with our past experiences with similar images."[57]

4.7 Sorting Visual Information

The brain deconstructs visual information for additional processing into *"what"* and *"where."* Within the brain there are two main "paths" used to sort visual information: the *"what path"* and the *"where path."*[58] Being able to identify "what" type of house is on fire would help firefighters recognize the distinctive internal (floor plan) and external (form) characteristics. Knowing "where" to go is relatively straightforward because the geometry of houses can be translated into a "cognitive map" or spatial mental model, of the house's floor plan – its paths of circulation and places (or rooms or "compartments," in firefighting jargon) and the relationship between the two.

The ***"what" pathway*** "is concerned with the nature of objects and faces; their shape, color, identity, motion, and function."[59] The ventral stream is the only visual pathway that is connected directly to the hippocampal formation, a brain area concerned with explicit memory of people, places, objects, and spatial navigation. The hippocampal system is also thought to act as a gateway into long-term memory (LTM).

The ***"where" pathway*** "is concerned with processing motion, depth, and spatial information to determine where objects are in the external world."[60] The dorsal stream performs a moment-to-moment analysis of the spatial location, shape, and orientation of objects in the visual scene.

Overall, visual processing proceeds in three steps.

Step 1: Low-level Processing (This happens in the retina). This first stage of bottom-up processing "detects the presence of an image."[61]

Step 2: Intermediate-level Processing (This happens in primary visual cortex, labeled V1 by brain scientists). According to Kandel, this step, "discerns which surfaces and boundaries belong to specific objects and which are part of the background."[62] Architects come to know this concept as the figure-ground relationship. Additionally, this step of visual processing is "designed to combine features into distinct objects" and this is the second stage of bottom-up processing.[63]

Step 3: High-Level Processing (This is the sensemaking phase). This last phase "integrates information from a variety of regions in the brain to make sense of what we have seen. Once this information has reached the highest level of the *what* pathway, top-down processing occurs: the brain uses cognitive processes such as attention, learning, and memory – everything we have seen and understood before – to interpret the information."[64]

Because visual information is disassembled into *what* and *where*, having two visual pathways poses a binding problem for the brain. The brain must reassemble visual information somehow. In *Reductionism in Art and Brain Science: Bridging the Two Cultures*, Kandel writes about studies by Anne Treisman that discovered attention and two additional processes – the *pre-attentive* and *attentive processes* – are required to reassemble visual information.[65]

Pre-attentive Process – Is "concerned only with the detection of an object. In this bottom-up process the beholder rapidly scans an object's global features – such as its shape and texture – and focuses on the distinctions between figure and ground by encoding all the useful elementary properties of the image simultaneously: its color, size, and orientation."[66]

Attentive Process – Is "a top-down searchlight of attention that allows higher centers in the brain to infer that since these several features occupy one location, they must be bound together."[67] Here, context and relevance matter a great deal.

Human performance researchers Philip Alexander Furley and Daniel Memmert describe attention in "The Role of Working Memory in Sport," as

> Analogous to that of a thermostat. A thermostat is set to a specified temperature and then activates the heating system automatically when the temperature diverges from the preset temperature without requiring any further intervention from the person who set the thermostat. Thus, the person controls the thermostat, but the control is executed off-line.[68]

One's cognitive abilities are limited when compared directly to the human perceptual ability. Cognitive neuroscientists Stephanie A. McMains and David C. Somers write in "Multiple Spotlights of Attentional Selection in Human Visual Cortex," that "what we perceive and what we fail to perceive is largely determined by attentional mechanisms that select information for enhanced cognitive processing."[69] This is especially true for firefighters operating at an emergency scene. Although there is evidence within the reviewed literature that the brain may be able to divide spatial attention. This "parallel processing is an implicit feature of spatial representations."[70] Over time, firefighters acquire knowledge and experience that shape one's spatial mental representations, or models.

The brain consciously (and unconsciously) learns *when*, *where*, *how*, and for *how long* to allocate its limited attentional resources within different contexts. Practically speaking, *context* "identifies the banks of prior knowledge" one uses to make inferences, and *relevance* "describes how this new information relates" to one personally.[71] It is the context that helps direct the mind's "searchlight of attention." At a neurological level, context reflects the activation of other neural circuits representing other events.[72] Every memory is "linked to a close, medium, and distant association."[73] Many of these memories are also connected spatially. Much of what one remembers takes place within a specific context and is situated in a specific place and time. Thus, one "can resolve the ambiguity of a retinal image accurately" because the brain stores the context.[74] It comes back to the brain – "context and relevance trigger the conscious mind to pay attention to remember" and know where to look to find the information it needs.[75] The visual system is predisposed to helping one identify "what" something is and "where" it is located. Although every individual's visual system will extract much of the same essential information from an environment, each firefighter will "see" and interpret the building differently. This thesis is an attempt to make what firefighters "see," interpret, and communicate more consistent, to the greatest extent possible.

Psychologist Barbara Tversky explains that "to make judgments about a space, people seem to extract the relevant information on the fly and integrate it using relations between elements relative to a reference frame."[76] A firefighter's frame of reference depends on the assigned task (for example, engine company, ladder company, or incident command) and on whether the task requires *sighted* or *visually impaired* movement. Over time, a firefighter develops a proficiency in interpreting spatial information with and without sight, but this is a learned (and perishable) skill. Wayfinding would not be possible without memory and the specific sequences of neural circuits that represent the environment within the brain.

PART 3 – HUMAN MEMORY PROCESSES

4.8 Wayfinding and Memory

While acknowledging that the following simplification of complex human memory processes is likely to omit essential information, it can be helpful to think about memory holistically – as multiple processes within mind that work together with other systems to extract features from the continuous flow of sensory information and store them for future use. The brain binds, or groups memories together into coherent associations and encodes, consolidates them for storage and retrieval. Human memory can be remarkable and enduring, but also corruptible and unstable at times. A detailed study of human memory processes is far beyond the scope of this thesis, but in trying to understand how firefighters wayfind, one must acknowledge from the outset that memory is an essential part of wayfinding, especially in smoke.

The brain is composed of a "team of rivals," and human memory is an illustrative example of this dichotomy — there is a constant battle between systems that seek to remember and those that seek to erase or forget. It is also important to acknowledge that "the world as we see it is a construct slowly built up by every one of us in years of experimentation."[77] All of this information is stored in memory, some parts of it consciously accessible, other parts inaccessible, or unconscious.

In smoke, firefighters must constantly make use of memory processes to keep track of their location, distance traveled, and direction of travel. Because firefighters cannot reasonably rely on vision for assistance to locate things, they have no choice but to keep track of everything in mind. Human memory, however, is limited, subject to interference, and has been shown to be shaky under extreme stress. This section presents a simplified examination of how one's memory is organized (and is affected by stress), in order to better understand how memory influences firefighters' perceptions, and thus, one's ability to wayfind in smoke (see Figure 4.2).

In "Episodic Memory and Common Sense: How Far Apart?" psychologist Endel Tulving writes, "research shows that it is perfectly possible for even completely sane, intelligent and honest people to clearly remember and strongly believe something that never happened."[78] Tulving continues by writing, "a good part of the activity of memory consists not in reproduction, or even in reconstruction, but in sheer construction. And constructed memories do not always correspond to reality."[79] The brain treats these "false memories" the same as "real" memories**.** This proves to be problematic in smoke where firefighters rely heavily mental simulation (i.e., imagination).

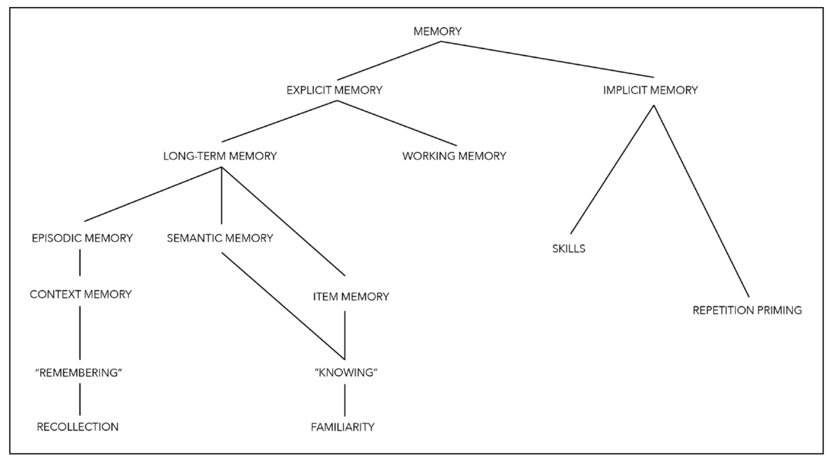

Figure 4.3 Organization of memory.[189] Reproduced from the *Neuroscience of Memory*, Slotnick.

Even though the details of one's experience "may be reshuffled and even replaced or distorted…as long as one has a temporal and spatial context on which to hang those details, along with having experienced the original episode firsthand in the past, an episodic memory should persist."[80] The floor plan of houses on fire represents a frame upon which the brain's mental simulation (and memory) processes can be reliably constructed, even in smoke.

Memory refers to the process of encoding, consolidating (storing), retrieving, and updating information. Neurolinguist Flavius D. Raslau, et al. write in "Memory Part 1: Overview," that

> Memory is not a singular process. It represents an integrated network of neurologic tasks and connections. In this light, memory may evoke comparison with an orchestra composed of many different instruments, each making different sounds and responsible for different parts of the score, but when played together in the proper coordinated fashion, making an integrated musical experience that is greater than the simple sum of the individual instruments.[81]

Memories are both *abstract* (in the sense that there are different ways a firefighter can access the memory) and *concrete* (in the physical sense, manifesting as neuronal connections within the brain). Memories "are a mix of fact and fiction. In most memories, the central story is based on true events," but the brain reconstructs it each time it is recalled.[82] Memories are somewhat of a construction. The types of memory the brain forms are organized as a dichotomy of sorts, for example: short-term and long-term. The brain is capable of forming two major types of memory – *explicit* and *implicit* – although each type of memory consists of additional memory processes. Implicit memory processes are integral to firefighters' ability to execute psychomotor skills on the fireground, but their study is beyond the scope of this thesis. This thesis will only examine parts of the brain's explicit memory process. What is important to note, however, is that explicit memories can be moved to implicit memory.[83] This thesis is an attempt to draw a number of explicit and implicit memory processes out into the open (e.g., how firefighters assess burning buildings and how they wayfind in smoke) in order to understand them.

***Explicit memory**,* "is a memory of people, places, and objects. It is based on conscious recall and requires the medial temporal lobe and the hippocampus." [84] *Long-term memory* (LTM) and *working memory (WM)*, considered a form of short-term memory, are explicit memory processes.

Implicit memory, "is the unconscious recall of motor skills, perceptual skills, and emotional encounters, and it requires the amygdala, the striatum, and in the simplest cases, the reflex pathways."[85] Implicit memory is not considered in detail in this thesis, but note that firefighters rely also on implicit memory during locomotion.

Within *explicit memory*, there are a number of other memory types, but of specific concern this thesis are its two primary divisions – *long-term memory (LTM) and working memory* (WM) and. *LTM* "refers to retrieval of previously presented information."[86] *WM* "refers to actively holding information in mind during a relatively short period of time."[87] WM, is "a form of short-term memory that integrates moment-to-moment perceptions" with more durable memories of past experiences.[88] Information activated in WM is quickly discarded if it is not salient. Kandel explains that "working memory is essential for exercising rational judgment because it enables us to control our emotions and to anticipate, plan, and carry out complex behavior."[89] During firefighting activities, working memory (WM) is the primary limiting factor in wayfinding tasks. Many of firefighters' skills have been trained to a point they become reflexive, or unconscious and automatic. Wayfinding, however, requires the integration of multi-modal sensory information, problem-solving, inductive (and deductive) reasoning, and decision-making. WM is implicated in the brain's ability to make sense of this environment, orient to essential features, and then navigate between points within it.

In "Processes of Working Memory in Mind and Brain," cognitive neuroscientist and psychologist John Jonides et al. explains WM,

> Working memory consists of buffers, each of which is responsible for storing information in some code. There is one buffer responsible for storing verbal information, one for visual or spatial information, and one for episodes, regardless of the modality of coding. The model further postulates that there are 'rehearsal' processes that refresh the information in storage and keep it accessible. Each of the buffers articulates with long-term memory, so information can enter working memory either from the outside world or from the contents of long-term memory. Finally, this model includes executive processes that manipulate information in the buffers in the service of complex cognition, such as mental arithmetic.[90]

British psychologist Alan Baddeley developed the above theory that describes WM as a "succession of storage systems in which information flows from the environment, into a series of temporary sensory buffers, which are essentially part of the perceptual process, before being passed on to a limited capacity short-term memory store, which then feeds long-term memory (LTM)."[91] This model describes how humans temporarily manipulate and store information during thinking and reasoning tasks. For example, firefighters carry spatial information (e.g., direction of travel (bearing), number of turns, distance traveled, relative position, and landmarks) in WM. Storage of spatial information competes for resources as the brain also monitors fire conditions and smoke behavior. The deeper a firefighter travels into the smoke, more information about the environment must be kept *activated*, or readily accessible. Researchers generally agree that the capacity of WM is limited. Within firefighters' brains there is a competition for attentional resources between higher-level decision-making processes and reflexive habitual responses. Of critical importance within the context of wayfinding in smoke is that the firefighter be able to rapidly integrate task-relevant perceptions and long-term memory (LTM), something that requires WM. In "The Role of Working Memory in Sport," researchers Philip Alexander Furley and Daniel Memmert describe WM in the following manner,

> WM is those mechanisms or processes that are involved in the control, regulation, and active maintenance of task-relevant information in the service of complex cognition, including novel as well as familiar, skilled tasks.[92]

Wayfinding is a skill that requires high-level cognitive resources. Within long-term memory (LTM), there are two additional subdivisions relevant to the thesis – *episodic memory* and *semantic memory*. Episodic memory "refers to the detailed retrieval of a previous episode."[93] *Semantic memory* "refers to the retrieval of factual information."[94] In this case, facts about the buildings firefighters operate inside provides essential context.

Wayfinding would not be possible without the ability to access and use spatial knowledge gained from previous experiences stored in memory. Neuropsychologist Hilde Ostby and novelist Ylva Ostby, sisters and authors who have studied and written about memory extensively, write in their book *Adventures in Memory*,

> Your experiences are taken into the brain, after that, the experience is taken apart and stored away in little pieces in the brain's neocortex. Every time you recollect it, it is brought back to life. The hippocampus is critical to reconstructing the memory in your mind's eye, enabling you to relive it once more.[95]

Their useful simplification describes a complex process involving multiple brain areas. For example, memories at a fire are encoded with auditory, somatosensory, visual, and spatial information. According to Raslau,

> The hippocampus holds a unified representation of the event and the auditory information is distributed to the superior aspect of the temporal lobe, the spatial information is distributed to the parietal lobe (inferior parietal lobule), and the visual information is distributed to the occipital cortex.[96]

Researchers have shown that the brain has an entire "system devoted to the processing of navigable space and have also shown that this system underpins memory for life events: so-called episodic memory."[97] *Episodic memories* are one's autobiographical memory. Neuroscientist Arne D. Ekstrom et al. write in *Human Spatial Navigation,* "episodic memory refers to specific, contextual details of personally experienced events that occurred at a particular point in time and at a particular place."[98] In "Episodic Memory: Neuronal Codes for

What, Where, and When,"Jorgen Sugar and May-Britt Moser write that "the binding of sensory stimuli into a cohesive and unique episodic memory likely depends on neuronal activity in the entorhinal cortex, that signals temporal relationships ('when'), a spatial universal metric ('where'), and the experience itself ('what')."[99] Sugar and Moser continue by writing,

> We can imagine a process where entorhinal cortex presents a 'movie' of ongoing experience to the hippocampus that acts as an editor of this continuous flow of information. In essence, hippocampus is able to extract and tag memorable moments of ongoing experience and consolidate them into memory. In this way, entorhinal cortex and hippocampus could contain the neural coding mechanisms that underlie our ability to form episodic memories.[100]

Although his area of expertise is music, in his book *Music and Memory: An Introduction* (published by the MIT Press), Bob Snyder builds his arguments on the work of recognized experts in neuroscience, cognitive science and related fields. Snyder's work summarizes brain science concepts within the context of music and performance. Firefighting and music are similar in regard to the influence memory has on skilled performance. Snyder uses a useful analogy describing episodic memory as "somewhat like a caricature of an experience, an example of how much the initial categorization (coding) of an experience shapes the memory of that experience."[101] With episodic memory, distortion is the rule, not the exception.

According to Ekstrom et al.,

> Episodic memory and navigation involve many similar core features. Perhaps most central to the intersection is the fact that navigation involves remembering past experience to facilitate how we navigate future routes. In particular, our ability to mentally time travel and imagine routes we have taken in the past is a core part of our ability to form rich, visually based maps. These maps in turn are a critical part of our ability to navigate efficiently using information we have formed from past experience.

For example, "the intimate relationship between episodic memory and spatial context has long been recognized though the ancient mnemonic practice of *method of loci*, which involves mentally assigning to-be-remembered items to salient locations along a familiar route."[102] Wayfinding often involves a high degree of familiarity with the environment, Ekstrom et al. write, "that we don't need to remember a specific instance of an event, but instead we need to know general properties of an environment to navigate within it."[103]

Human memory has "considerable redundancy built into the recall process, at least for memories with rich, active contexts."[104] Fortunately, firefighting practice allows for the development of vivid memories with emotional significance, and multiple associations between other memories. To gain access to memories, the literature cited by Snyder (and others) describes "three types of *cuing*: (1) ***recollection***, where we intentionally try to cue a memory; (2) ***reminding***, where an event in the environment automatically cues an associated memory of something else; and (3) ***recognition***, where an event in the environment automatically acts as its own cue."[105] Snyder states that the "real challenge of long-term memory is to retain the association between a specific cue and a specific memory over time."[106] This is the crux of the wayfinding in smoke problem.

Recent research suggests that "the complex, contextual, spatial, and temporal memory system does not behave in a 'business-as-usual' manner when the stress level is extremely high."[107] Conditions of extremely high stress — whether environmental, in this case smoke and fire, or psychological, such as the fear of getting lost in the smoke or fear of the unknown — triggers a cascade of chemicals that may affect the functioning of the brain's primary spatial processing systems.

4.9 Memory Processes Under Stress

It is largely accepted that the brain processes information using two "systems." These systems are described in neuroscience literature and by psychologist Daniel Kahneman. One of these systems is *fast* (largely unconscious) and the other is *slow* (deliberate, conscious).[108] The brain processes information in specific ways shaped by the manner in which each system works. *System 1* is an "automatic, autonomous, stimulus-driven, fast operating mode."[109] *System 2* is modulated by "will and attention," and is possibly algorithmic in nature.[110] It operates more slowly in a sequential manner using short-term (working) memory. Kandel explains that,

> "The brain first processes the information it receives from the sensory organs: information about vision from the eyes, sound from the ears, smells from the nose, taste from the tongue, and touch, pressure, and temperature from the skin. It then analyzes this incoming sensory information in light of past experience and generates an internal representation, a perception of the outside world. When appropriate, it initiates purposeful action in response to the information it has received. In this way the brain integrates all aspects of our mental life – perception of sensory information, thought, feeling, memory, and action."[111]

The human physiological response to stressful stimuli has been studied extensively by numerous researchers. The sympathetic nervous system (SNS) is generally associated with the "fight or flight" response to acute stress. It prepares the body and mind to respond to perceived danger. Responding to a fire elicits a SNS response. Kandel explains how researchers studying responses to emotionally-charged stimuli, "found that the intense emotion caused by either a perceived threat or a perceived reward triggers an undifferentiated arousal — a primitive emergency response that mobilizes the body for action."[112] The "fight or flight" response "reflects the limited choice available to our ancestors when reacting to either a threat or a reward.[113] Kandel writes that, "we first process an emotional stimulus from the bottom up, at which point we experience increased heart rate and respiration, causing us to flee from the bear; then we process the emotional stimulus from the top down, at which point we use cognition to explain the physiological changes associated with our flight."[114] The stress response associated with certain activities (for example, firefighting, base jumping, big-wave surfing, and so forth) has been shown to have "both enhancing and impairing effects on memory, depending on the specific memory process or stage that is affected by stress" (i.e., the stages include *encoding*, *consolidation*, storage, *retrieval, and updating*).[115]

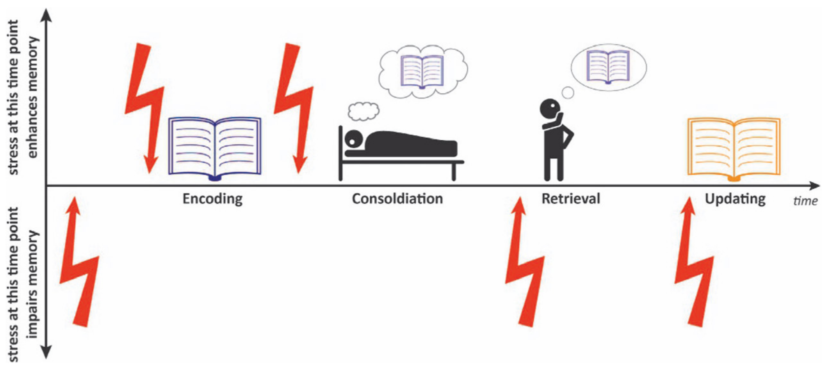

Figure 4.4 Learning and memory under stress. Psychologists Susanne Vogel and Lars Schwabe write, "while stress (indicated as red flash) long before encoding impairs memory formation, stress shortly before or after the presentation of new information generally enhances subsequent memory performance. In sharp contrast, stress before memory retrieval impairs the recall of information learned previously which may directly affect performance."[190]

In "Learning and Memory Under Stress: Implications for the Classroom," memory and stress researchers Susanne Vogel and Lars Schwabe write that the chemicals released during a "fight or flight" response have "profound effects on attention, working memory, and long-term memory."[116] Vogel and Schwabe write that the "effects of stress on memory depend on the specific memory process investigated and the temporal proximity between the stressful event and this memory process" (see Figure 4.3).[117] Schwabe, et al., write in "Mechanisms of Memory Under Stress," that

> Stress effects on memory may only be understood when taking the differential contributions of multiple anatomically and functionally distinct memory systems into account and that stress will influence memory over a wide range of time, from the initial memory encoding phase, through consolidation to storage, even months after the stressful event.[118]

In general, little is known about firefighters' memory processes. Additionally, there exists little scholarship on the performance of firefighters' memory under stress. One notable exception is a study performed by cognitive psychologist Janet Metcalfe and her team of researchers at Columbia University, who worked with the Fire Department of New York (FDNY) to study firefighters' recollection of events *after fires*.[119] There exists no research literature about how firefighters taught to recognize spatial features an environment *before* a fire or how they may use that information *during* fire suppression and search/rescue operations. Metcalfe et al., presented the findings in "Memory, Stress, and the Hippocampal Hypothesis: Firefighters' Recollections of the Fireground." Metcalfe et al., write,

> The hippocampal system in animals seem to provide the scaffolding needed for an episodic memory system such as that which underpins human mental time travel, as Tulving (2005) has referred to as autonoetic consciousness. Autonoetic consciousness is a type of awareness that involves recollection of personal contextually bound episodic memories, and mental time travel into both the past and future.[120]

Current research into the hippocampal system in rats, seems to support a mental time-travel system in humans. The hippocampal hypothesis proposed by Metcalfe et. al. posits "that under conditions of extremely high stress hippocampal functioning is impaired, and this results in a kind of acute amnesia specific to the episodic/autonoetic system."[121] Metcalfe et al. continue,

> The idea that under conditions of extremely high stress something special happens to memories is common to both the Freudian perspective and to the 'hippocampal' hypothesis. But *what* happens is different…by the Freudian view, the traumatic memory is pristine and replete but buried — awaiting recovery. By the hippocampal view, when the hippocampus becomes dysfunctional because of the influx of glucocorticoids associated with extremely high stress, episodic memories are likely to become fragmented (because of a binding failure) or may fail entirely to be recorded. If a spatially and temporally coherent representation is not encoded, then, by the encoding specificity principle (Tulving & Thomson, 1973), even the best retrieval cue will not provide access to it. Thus, there is no possibility of uncovering of a true coherent narrative episodic memory trace. The trace laid down under conditions of extreme stress is something like a photograph taken by an extremely jittery hand and projected onto overexposed film — blurry, fragmentary, and incomprehensible at the outset and subject to forgetting, overwriting, interference, and distortion induced by subsequent events.[122]

What this means that the episodic memory system firefighters rely on heavily, can be problematic, or unstable, under extreme stress. Firefighters must find their way in an environment where decisions based on corrupted perceptions and memories can have fatal consequences. If, as the hippocampal hypothesis proposes is true, firefighters' episodic memory may be problematic under extremely stressful conditions. If that is the case, "precautionary measures and training to offset this human fallibility" are necessary.[123] This thesis addresses the fallibility of episodic memory and the concerns posed by Metcalfe et al., directly — by proposing a catalog of house types designed to assist firefighters in making rapid, accurate, and consistent interpretations and predictions about the spatial organization of house types *before* they step into the smoke.

4.10 Mediating and Modulating Systems

Research into the brain's neuroelectric and neurochemical processes and associated neurotransmitters, has allowed scientists to understand the biological basis of vision, emotion, and the brain's ability to make predictions about one's environment. According to Kandel, all humans share basic neural circuits, referred to as *mediating systems*.[124] The brain also has *modulating systems*, which "modify the action of mediating systems: they do not turn them on or shut them off. In this way they are like the volume dial, rather than the on-off switch, of a radio."[125] The various modulating systems, according to Kandel, "release different neurotransmitters, each with different physiological and behavioral effects."[126] Kandel writes,

> The key bottom-up modulating systems are the familiar *dopaminergic system*, which is involved in the anticipation or prediction of learning-related reward or in the registration of surprising, salient events; the *endorphin system*, which gives rise to pleasure and blocks pain; the *oxytocin-vasopressin system*, which is involved in bonding, social interaction, and trust; the *noradrenergic system*, which is recruited for attention and novelty seeking, as well as certain types of fear; the *serotonergic system*, which is involved in a variety of emotional states, including happiness, and sadness; and the *cholinergic system*, which is involved in attention and memory storage.[127]

Additionally, there are a number of brain areas important to prediction, emotion, and ultimately to sensemaking – the ***striatum***, the ***prefrontal cortex (PFC)***, the ***amygdala***, the ***hypothalamus***, and the ***hippocampus.***[128] Together, and with others, these brain areas work to coordinate the perceptual and cognitive response to an event, and they help firefighters remember it and make sense of it (from the top-down). The *striatum initiates* a course of action, "fight or flight" (i.e., often referred to as "approach or avoidance" in brain science literature). The striatum relies on information it receives from the prefrontal cortex. The *prefrontal cortex (PFC)* is the key to planning complex behavior, whose job is to evaluate goals, rewards, punishment, and organize one's behavior. The PFC is unique in its ability to take in vast amounts of information. It sorts and organizes it so it makes sense and has meaning; and does so repeatedly. During the event, the *amygdala*, an area of the brain that contributes to emotional processing (it also seems to orchestrate the emotional response), sends a signal to the *hypothalamus*, where nerve cells are housed that control instinctive behavior. The hypothalamus "functions like a command center, communicating with the rest of the body through the nervous system so that the person is prepared to fight or flee."[129] And the *hippocampus* is implicated in memory processing, specifically spatial memory. Wayfinding, "involves the building of a complex knowledge space and learning how to use tools to read it, and after learning, the role of the hippocampus is to support remembering prior experiences in the space as a guide to planning navigational decisions."[130]

Without these brain areas, the firefighter could not take the standard information from the visual system (bottom-up processing), make sense of it (top-down processing), and formulate a plan of action under acute stress. They are critical to sensemaking, and ultimately wayfinding in smoke. Firefighters are expected to assess and respond to emergency situations in a predictable manner. The reality is that firefighters are human. They are programmed, largely through training to suppress the natural human response to danger – which is to flee. Humans first respond to a stimulus emotionally. There is a direct line of communication between the sensory thalamus (which is a relay for sensory inputs) to the amygdala (which processes emotion) and to motor neurons. In the environment in which firefighters operate, unique individual interpretations, inaccurate predictions, and uncontrolled physiological and emotional responses to acute stress can lead to perceptual and cognitive impairments, confusion, poor decision-making, disorientation, and death.

4.11 The "Ganzfeld Effect"

Lacking clear percepts, which is common in smoke, the brain amplifies what little information the retina does receive and reaches back into its own memory banks for information needed to construct its hypotheses about what to do next and where to go. Smoke, effectively makes the environment unstructured, meaning that there are less-readily apparent landmarks. As a result, one's perception is affected. The "image" that is sent to the brain by the eyes is interpreted differently in the brain and it does not take long for the brain to start changing its own perceptions. In this case, it seems to be faster and easier for the brain to reach back into memory storage for sensory information than it is to find it in the environment.

Like a pilot flying in thick cloud cover, a ship captain navigating a dense fog, or a mountaineer caught in whiteout conditions of a snowstorm, the firefighter experiences a similar visual deprivation inside a burning house. This deprivation is called the *"Ganzfeld Effect."* Introduced by psychologist Wolfgang Metzger, the Ganzfeld Effect happens "when your brain is starved of visual stimulation and fills in the blanks on its own. This changes your perception and causes unusual visual and auditory patterns. It can even lead to hallucinations."[131] The effect results from uniform and unstructured stimulation, a condition commonly found inside buildings on fire.

A fire produces smoke as a result of incomplete combustion. This smoke is composed of toxic chemicals, vapors, fumes, oils, and particulate matter. Visibility is dictated by the extent of fire, the ventilation profile, the configuration of rooms, and one's position within the environment. Smoke makes navigating more difficult, movement slower, and imposes greater cognitive demands on the firefighter. While wayfinding in smoke, visual information is ambiguous at best. Sometimes, the smoke obscures everything, effectively creating a uniform visual field. In an environment filled with smoke, sensory details matter a great deal. The characteristics of the smoke can also be helpful. Inside, it is the speed at which the smoke moves, in addition to its turbulence, its volume, its density, and its color that provides critical information upon which decisions are based. For example, a uniform and unstructured stimulation can be indicative of an early-stage fire that lacks ventilation or one that has been sprinkler-controlled. Smoke that is uniform in color and brightness means its movement is often imperceptible. Uniform color smoke is the kind created by theatrical smoke machines firefighters use in training, thus robbing firefighters of the opportunity to support their "educated guesses" with information gleaned from the smoke's behavior. Real smoke is typically limited to live-fire situations and many fire departments do not have a facility equipped or designed to set fires repeatedly inside. Live-fire training, surprisingly, is relatively rare.

The "Ganzfeld Effect" describes how the brain responds to the lack of clear percepts. As the artist James Turrell writes, "when this occurs for an extended period, the person is subject to phantasmagoric hallucinations: the 'prisoner's cinema' experienced in isolation cells or collapsed mines."[132] For example, firefighters consistently report that spaces seem larger than they are; that depth perception, travel distance, that position and bearing estimates are easily distorted or wrong; and that familiar objects are unrecognizable in smoke. Anecdotally, firefighters make statements like "that was not what I thought it looked like" or "I had no idea the room was this small" all the time. Reports of perceptual and memory distortion are ubiquitous in firefighting practice.

The "Ganzfeld Effect" effectively shuts down the visual system and which can influence decision-making, sometimes with fatal consequences. Smoke obscures the environment in ways that have profound effects on the speed of movement through a space, orientation, navigation, and on survivability — both for the civilian and for the firefighter.

PART 4 – THE BRAIN'S SPATIAL MENTAL MODELS

4.12 Sensemaking Systems in the Brain

The brain creates models about everything — from the environment to the body to social relationships — in order to make sense of the confusing and disparate array of sensorimotor inputs. Of concern to this thesis are the spatial mental models the brain creates about houses on fire. In smoke, the environment lacks distinctive, easily identifiable features or landmarks. A firefighter who cannot make sense of the situation and environment risks getting lost, and getting lost, even inside a house, can be fatal. Firefighters get lost inside houses for a number of reasons, but it is likely to be a combination of the spatial organization of the house, the mental model(s) that the firefighter constructs as they navigate, the wayfinding strategy (which is chosen under stress and time-pressure), and the person's spatial ability. Neuroscientist Colin Ellard writes in You Are Here, "we often become lost because we cannot keep track of our position by remembering our own movements."[133] Firefighters are able to wayfind in part because certain systems within the brain are directly implicated in recognizing, remembering, and making sense of spatial relationships (see Figure 4.4).

The ***entorhinal cortex*** "provides a spatial ('where') and temporal scaffold ('when') of ongoing experience."[134] The ***hippocampus*** deals with "'allocentric' space, which is organized relative to the outside world."[135] The hippocampus seems to play an essential role in guarding memories while they mature and solidify and then facilitates entry into and retrieval from LTM. The hippocampus is also "known to be involved in long-term memory, spatial processing, temporal processing, and novel stimulus processing."[136] It has been said to be involved in memory reconstruction too. This brain structure is well-known through research regarding the impressive spatial memory of London Taxi drivers.[137] The hippocampus has been shown to create a more "flexible 'cognitive'" representation of the environment.[138] The ***parietal lobe*** "involves space that has a specific and fixed relationship to the body" – "egocentric" space.[139] The parietal lobe "is not a permanent store for information about the location of the items relative to each other, but is needed to represent where they are in egocentric (self-related) spatial coordinates."[140] According to neuroscientist Kate Jeffrey, the ***striatum*** "dominates in behavior control whenever the behavior is familiar, well-rehearsed and does not require much flexibility of thought."[141] A "more rigid, 'habit-like'" response to the environment is based on the striatum.[142]

Overall, largely because of the brain's entorhinal-hippocampal system (but in combination with other processes and neural networks), it is believed that the brain is able to create dynamic spatial mental models about the environment and make sense of this environment. The next page illustrates a number of the brain areas that are implicated in wayfinding and sensemaking.

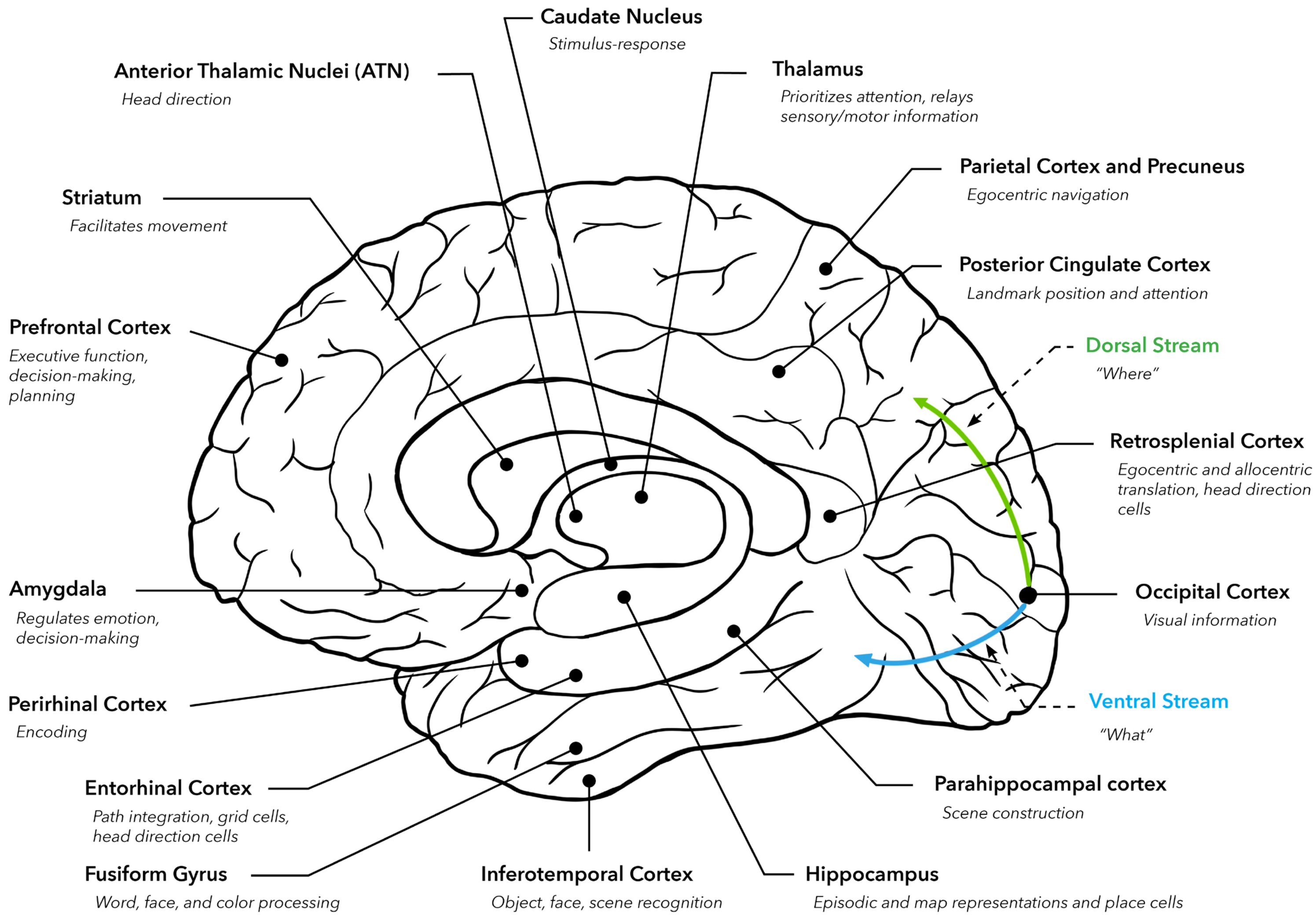

Figure 4.5 Anatomical Representation of the Brain's Spatial Areas. Jordan C. Legan illustration based on Coughlan, page 499.[191]

4.13 Cognitive Maps and Spatial Mental Models

Firefighters have limited navigational tools at their disposal. Firefighters do not use a compass, maps, or Global Positioning Satellite (GPS) for wayfinding inside a burning house. The development of thermal imaging cameras (TICs) has been helpful, but those too come with their own set of problems. For example, at any incident, there may only be a handful of TICs available to use. TICs are not issued to every member on the fireground. Their screens are small, they cannot see *behind* (due to occlusion), *through or under objects* (TICs register heat energy through the principle of emissivity), or *help the user accurately judge depth*. Additionally, TICs have multiple functional "modes" related to the device's thermal sensitivity. For example, *high* or *low sensitivity*. Each mode is associated with a number of color palettes that vary somewhat by device and manufacturer. TICs have a limited "field of view," one that dictates the mode the TIC will operate within. TICs have an nuanced "language" which requires firefighters be taught to know and understand.

Relating the TIC's navigational utility back to brain processes, each eye individually (and both eyes collectively) have a field of vision (FOV), similar to that of the thermal imager. According to Kandel, "the image on the retina of each eye is two-dimensional, like a painting or a film, yet we see a three-dimensional world. How do we

Image 4.6 A thermal imaging camera (TIC) in use after a fire. This image illustrates a depth disparity between vision and the image provided by the TIC. Jordan C. Legan photo.

Image 4.7 This is the TIC image from a photo shown earlier in Chapter 3 (Image 3.5). The TIC is in the "low-sensitivity mode" looking toward the approach span from the entry span. Nozzle Forward photo.

achieve this perception of depth? The brain uses two major types of cues: monocular cues and binocular disparity cues."[143] Kandel writes "much of depth perception, including perspective, can be obtained from monocular cues" such as *occlusion*, *linear perspective*, *relative size*, *familiar size*, and *aerial perspective*.[144] Smoke obscures the environment in such a way that the brain cannot accurately determine depth using such cues without vision. The TIC allows for partial "vision," but *depth* (a critical part of orientation) is distorted, as evident in Figure 4.5. The speed with which objects can be recognized (i.e., acknowledged as "familiar") takes longer in smoke than with vision. In smoke, the user must scan the scene with the TIC, sometimes multiple times, and/or confirm by "feel" in order to recognize features of the environment. Additionally, TICs are subject to failure like any technological device. Training to use the TIC is lacking industry-wide, but with proper training, TICs are an extremely valuable wayfinding and life-saving tool. The lack of training and availability means that firefighters rely heavily on intuition gained through first-hand and vicarious experience. As a result, firefighters may represent a modern primitive navigational culture.

Navigation in this environment happens largely without the aid of navigational technology (aside from protective equipment and SCBA). What this points to, is that firefighters rely on established wayfinding practices (i.e., rituals) and knowledge (i.e., cues and expectations) handed down to them by generations of firefighters before. They also create elaborate representations of their experience in mind, including of the buildings they have fought fires in.

Behavioral neuroscientists Elizabeth Marozzi and Kathryn J. Jeffery, in "Place, Space and Memory Cells," write "spatial cognition requires an internal representation of the outside world, an idea that dates back to Tolman, who in the 1940s proposed the existence of such a representation — which he called a *cognitive map* — to explain the flexible navigation behavior he observed in rats."[145] According to psychologist Edward C. Tolman, a cognitive map is "a mental representation of the position and spatial relations among multiple landmarks in the external world."[146] The brain "works over" and elaborates on incoming sensory information, meaning that the representation, or mental model "is independent of exact sensory information."[147] It is an approximation of the environment. In "What is a Cognitive Map? Organizing Knowledge for Flexible Behavior," neuroscientist Timothy E.J. Behrens et al. write, "cognitive maps can be constructed from general patterns of abstract relations that are separated from sensory representations and therefore generalize across different sensory environments. These abstract representations can be considered basis sets for describing relational knowledge."[148] To the best of this researcher's knowledge, firefighters' representations have never been studied.

Firefighters need a method to describe and ground their experience (i.e., their episodic memories) to something stable – to the floor plan of the building – which might be considered the basis of firefighters' "cognitive maps." The term "map," however, can be misleading and a cause for unnecessary confusion. People assume (often incorrectly) that a "map" records accurate metric information and that one can use it to navigate from one point to another. The nature of a "map" can be any number of things. For example, in his book *Maps Are Territories: Science is an Atlas*, social scientist David Turnbull, writes that *maps* are "*selective*: they do not, and cannot, display all there is to know about any given piece of the environment.[149] He continues, by writing that maps "are a graphical representation of the milieu, containing both pictorial (or iconic) and non-pictorial elements. Such representations may include anything from a few simple lines to highly complex and detailed diagrams."[150]

The proposed catalog of house types should *not* be considered a metrically accurate and detailed map in that regard, but rather a model that seeks to "capture the categorical spatial relations among elements [of the house] coherently, allowing perspective-taking, reorientation, and spatial inferences."[151] This thesis advocates for something more flexible than Tolman's original definition of the "map" in the brain. Tversky In "Cognitive Maps, Cognitive Collages, and Spatial Mental Models," argues in support of a less-restrictive definition of the brain's internal representation of the world,

> Like many useful concepts, the term cognitive map has many senses, leading to inevitable misunderstandings. One prevalent sense is that cognitive maps are maplike mental constructs that can be mentally inspected. They are presumed to be learned by gradually acquiring elements of the world, first *landmarks*, pointlike elements, then *routes*, linelike elements, and finally unifying the landmarks and routes with metric *survey* information.[152]

In an effort to eliminate complication and avoid unnecessary explanation, this thesis will use the term "***spatial mental model***" when referring to internal representations instead of "cognitive map" or "map." This author acknowledges that the term "spatial mental model" is likely to be met with some consternation by firefighters due to its academic connotations. But this distinction is made because the term spatial mental model better captures "relations that are easily comprehended from language as well as from direct experience."[153]

4.14 The Brain's Positioning System

In 2014, scientists John O'Keefe, May-Britt Moser, and Edvard I. Moser, received the Nobel Prize in Physiology or Medicine "for their discoveries of cells that constitute a positioning system in the brain."[154] The discovery of a network of cells that underly human spatial understanding was ground-breaking because it allowed researchers to peer inside the brain's complicated processes related to the construction of spatial mental models which seem to assist wayfinding (see Figure 4.5). According to cognitive neuroscientist Russel A. Epstein et al., in "The Cognitive Map in Humans: Spatial Navigation and Beyond," in order for the spatial mental model to be useful, there must be a mechanism that connects spatial mental model to "fixed aspects of the environment that can be identified by the body's perceptual systems."[155] These cells seem to perform that function. Secondarily, the model must,

> Include a mechanism for planning a route to one's destination. At a minimum, this involves calculating the distance and direction to the goal. Moreover, in many environments, routes cannot be direct because of obstacles in the terrain. The capacity to take efficient detours around these obstacles and to identify useful shortcuts is the crux of what a cognitive map provides.[156]

Within the brain's neural networks, there are special types of cells aptly named – *place*, *grid*, *border*, *head-direction*, and *speed cells* – whose job it is to help the brain orient and navigate an environment. It is hypothesized, based on research in rodents, specifically rats, that humans have similar cells which are part of a network that creates spatial mental models.

Place Cells fire in response to one's current location but also locations one had visited earlier. These cells accept inputs from many other sensory systems which are combined into a universal (supramodal) representation that "includes landmarks, compass cues, boundaries, linear speed, angular speed and so on, which are then passed to the place cells to exert different effects."[157] The brain groups these universal representations into three broad, but useful classes: First *external positional information* used for self-localization. Second, *contextual cues (non-positional)* which help the cell "disambiguate the environment."[158] Third, *movement information* which updates position through a "process known as *path integration*."[159] This third class of representations includes "vestibular signals, proprioceptive signals, optic and other forms of sensory flow, and information about commanded movements."[160] According to Jeffery, "a place cell needs to know about the 'context' – that is, which environmental or situation" one is in.[161] Place cells are active in different contexts and types of tasks.[162]

Present research suggests that ***Grid Cells*** are consistently updating distance and direction. These grid cells, fire at regular intervals as a rat traverses an open area, creating a hexagonal grid with coordinates similar to those in a global positioning satellite (GPS). When grid cells work together, they form something of a coordinate system for the spatial model. Grid cells "seem to represent space at different scales" and thus can be thought of as a sort of coarse and fine "metric" of space.[163] Each grid cell "forms a unique pattern of coordinates, which is shifted with respect to the coordinates formed by other nearby grid cells. In this way, the whole environment is 'filled' with grid patterns."[164] The researchers discovered that the points where grid cells fired mapped out a grid of equilateral triangles. Tversky notes that "grid cells can be reused, recalibrated, and reoriented."[165]

According to Ekstrom et al., *disorientation*, "which is a lack of knowledge of our position relative to other objects in our surroundings, can lead to significant confusion and in some extreme cases, death."[166] Tversky writes,

> Place cells and grid cells, underlie spatial disorientation as well as spatial orientation. Losing either can be disorienting: not recognizing your surroundings, a feat that depends on place cells, or not understanding how your surroundings fit into the larger world, a feat that depends on grid cells.[167]

Then there are, ***Head-Direction Cells*** which provide the brain a sense of direction. Marozzi writes, "head-direction cells, then collectively act like a neural compass. Unlike a real compass, however, the cells are not affected by the Earth's geomagnetic field, and firing directions are tied to a local reference frame, which is — as with place cells — defined by contextual cues and oriented by landmarks."[168] These cells tell the "hippocampal system which direction is which."[169] Researchers believe that these cells "depend on a continuous interplay between information coming from stationary environmental features — landmarks — and information coming from" movement.[170]

Marozzi writes that boundaries are of high importance to the spatial mental model. ***Border Cells***, or boundary cells, give the one some sense of the structure of the surroundings — essentially how big that space is. Their firing fields appear to be adjustable as the environment changes. The structure of the firing fields "is perhaps somewhat mosaic-like."[171]

When one moves, activity is shared between grid cells in accordance with one's displacement in the environment. In order to share information, grid cells must have continuous access to information about instantaneous running speed — ***Speed Cells***. The "information encoded by these speed cells provides exactly what grid cells need for position to be updated dynamically during movement."[172] Firefighters are acutely aware of the need for accurate directional references and of a method to judge speed and elapsed time.

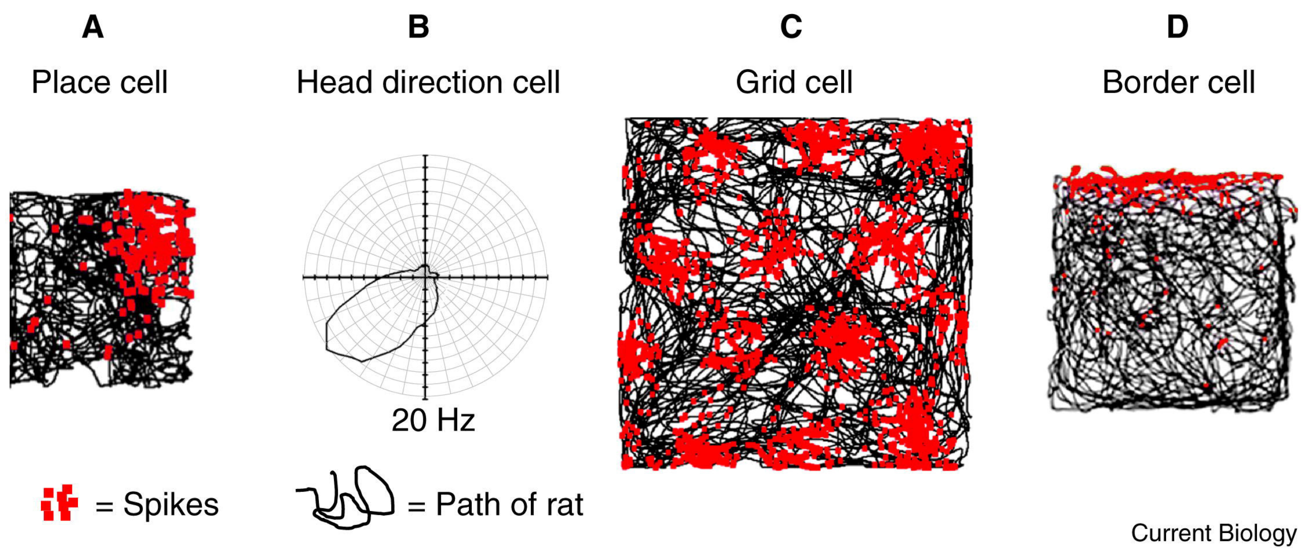

Figure 4.8 Cells in the brain associated with spatial navigation and orientation. Typical firing patterns of the major cell types in the cognitive map.[192]

Researchers do not yet know exactly how the mind constructs its spatial mental models or how exactly how they are used for navigation. Regardless, it is clear that the brain integrates information from all the senses to calibrate the internal models with the environment. "This whole navigation system in the brain allows us to perform complex navigation tasks in a smooth and seamless manner."[173] Jeffery writes,

> The brain separates out the business of spatial-processing in a modular way, with landmark-processing handled by one circuit, self-motion by another, direction by another, distance by yet another, and so on. We have also learned that these modules interact at so many levels that in some senses they aren't really modules at all, so much as criss-crossing rivers of information flow.[174]

Research using rodents (and human subjects) has provided many valuable insights into the brain's capabilities. This is an emerging field of study that has advanced quickly in the last three decades. Overall, based on the scholarly literature, it seems that brain creates a skeletal model of an environment that gets modified to fit the specifics of the new environment using all of the above cellular tools.

Wayfinding relies on the construction and storage of elaborate and detailed spatial mental models. Ekstrom, et al. write:

> While navigating, we become familiar with an environment and acquire knowledge about it, thereby extracting information from it and storing this information in our memory so that we can recall it later for a variety of purposes. In this way, navigation is a dynamic process. The process, which involves attention and memory among other cognitive capacities, can be quite rapid, particularly if we view useful features, like landmarks, by scanning the environment; it can also take time, depending on the size of the environment.[175]

In "Getting Lost in Buildings" Laura A. Carlson, et al. writes that "a large literature exists to show that this map [referred to as a spatial mental model in this thesis] is not a veridical representation. We might highlight the following components, as they apply specifically to navigation in a building:"[176]

First, there is a prioritization of certain features, objects, and landmarks. When navigating inside a house (or any building for that matter), firefighters encounter numerous rooms, corridors, intersections, and objects and they use a subset of these as landmarks to help them find their way in smoke.

Second, there is a simplification of the space, with a regularization of distances, angles, and spatial organization both within and between floors.

Third, firefighters typically assume that the organization of a given floor extends to all floors. The have difficulty updating their mental model when this assumption is violated. This can be problematic because floors in houses rarely share the same floor plan. The same can be said for the times when firefighters enter the burning house from a window or from a point other than the main entrance (for example, the back or side door).

Fourth, firefighters maintain a representation of their current position, updating it as they move and encoding information with respect to this new position but no longer maintain their current position relative to the previous one. In other words, firefighters do not update their position with respect to previous ones well. This can be attributed to the brain's limited working memory (WM) capacity.

Wayfinding requires that one acquire knowledge about the environment and update it periodically with new information, "including the spatial layout of salient landmarks, based upon visual, proprioceptive, and kinesthetic inputs. This information is encoded and stored in memory, allowing one to retrieve it in order to find the way back to a desired location within the same environment."[177] Epstein et al. write, "route planning involves considering the future using representations that were laid down in the past."[178] Vogel and Schwabe write,

PPC – Posterior parietal cortex.

RSR – Retrosplenial region.

EC – Entorhinal cortex.

HC – Hippocampus.

IT – Inferotemporal cortex.

PFC – Prefrontal cortex.

PFC – Prefrontal cortex.

PR – Parahippocampal region.

Thal. – Thalamus.

VC – Visual cortex.

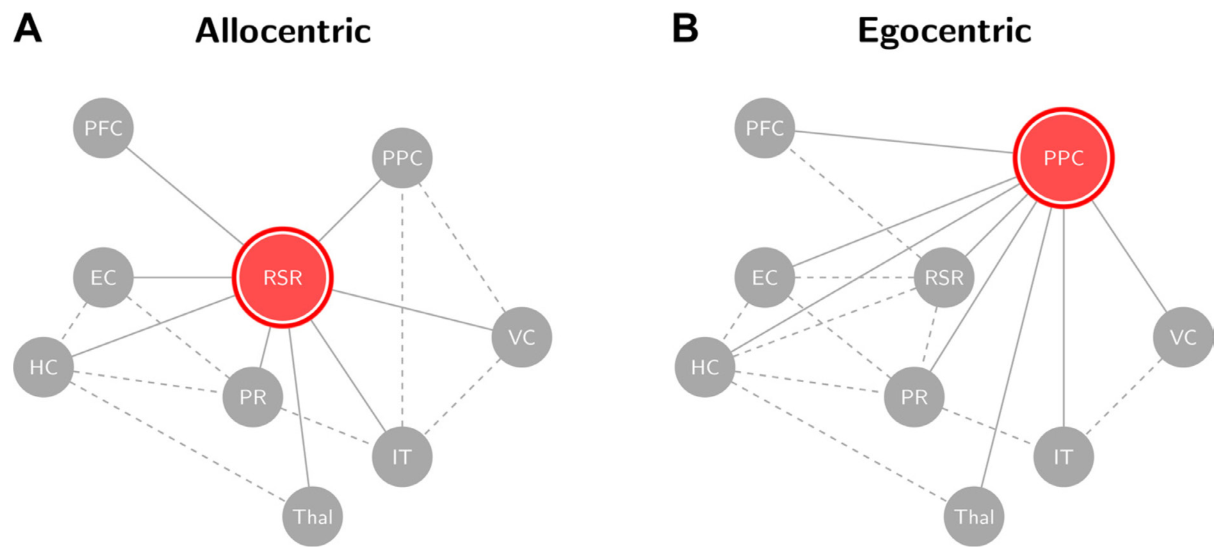

Figure 4.9 Allocentric and egocentric representations involve information processing centered on different hubs yet still involve largely overlapping brain regions. The schematic allows for heuristics, which will involve additional contributions from areas such as IT.[193]

Integrating new information into existing memories is a key process in education (as well as life in general where we are constantly required to update our knowledge). Such updating implicates that memories remain malleable even a long time after they have been formed initially and research over the past 15 years shows that this is indeed the case. There is compelling evidence that consolidated, seemingly stable memories return to a labile [easily altered] state when they are reactivated, which requires the re-stabilization of those memories in a process called reconsolidation. During reconsolidation, the reactivated memory can be weakened, strengthened, or altered. In other words, reconsolidation most likely represents the mechanism underlying memory updating processes. As reconsolidation involves the hippocampus and the PFC [prefrontal cortex], areas that are main targets of stress modulators, it seems reasonable to assume that stress would also affect reconsolidation.[179]

During wayfinding, the brain will construct an internal spatial mental model of the environment. Wayfinding is a dynamic and complex whole-body operation that relies heavily on multiple brain processes and regions (see Figure 4.8). Processes are made more complex by the smoke and the time-sensitive nature of the emergency. If firefighters have a basic understanding of what is happening in the brain, they are likely to recognize when, where, and their spatial navigation system is subject to failure and distortion. Armed with this information, firefighters can adjust their thinking and respond accordingly.

Ekstrom, et al., write,

> The computations underlying navigation, such as allocentric versus egocentric representation, involve small switches in the interactions of groups of neurons within each of these different brain regions.[180]

In "Interacting Networks of Brain Regions Underlie Human Spatial Navigation: A Review and Novel Synthesis of the Literature," Ekstrom et al., write,

> Human spatial navigation is better conceived of, behaviorally at least, as a highly dynamic process that more closely involves the use of heuristics and a continuum of egocentric and allocentric topological spatial representations rather than discrete, modular, metric representations.[181]

The defining characteristic of human spatial mental models seems to be the flexible expressions of memory within the brain.

4.15 Conclusion

Human minds have evolved the ability to "make instant decisions by combining partial information with rules of thumb, with assumptions, with normal expectations."[182] None of this is possible without memory. The brain fills in the gaps by performing multiple complicated perceptual and cognitive operations. The brain's processing systems create unique interpretations of sensory information. What is clear, however, is that "evolution hardwired humans to pay attention to certain stimuli more than others and, as adventure athletes have discovered, nothing catches attention quite like danger."[183] To wayfind in (and make sense of) dangerous, acutely stressful situations, one must first learn the "rules of the environment."[184] Firefighters are not taught the "rules" behind the brain's perceptual, cognitive, and memory processes and how they may influence wayfinding. Nor do firefighters learn the "rules" of the built environment. As a result, firefighters are regularly closer to disorientation and a collapse of sensemaking than necessary. With acute stress, comes diminishing perceptual and cognitive function. A collapse of sensemaking in this environment happens on a scale – from less consequential instances to instances of great significance.

Within brain science literature, it is well-established that the brain processes all objects (and even events) by generalizing and categorizing them. The brain disregards details that are perceived as behaviorally irrelevant in a given context. It attempts to abstract the essential, relevant (to the task at hand), constant features of objects, people, and landscapes and regularly compares the present image to images encountered in the past. Essentially, the brain sorts sensory information according to which information is most vital for understanding risks in the surrounding environment. The mind creates "working hypotheses." More than most people, firefighters find themselves in positions where the brain must make sense of ambiguous sensory inputs, shaky percepts, and memories that have the potential to be false. Therefore, it is imperative that firefighters construct accurate spatial mental models. Memory, as was shown, is not static, rather it "is largely a process of reconstruction" which has serious implications for firefighters tasked with maintaining orientation and navigating inside the burning house.[185]

Chapter 5 proposes a novel solution to the problems outlined in this chapter – the catalog of house types. It proposes that firefighters be taught to identify a number of distinct spatial patterns of cues, as illustrated in the catalog. The catalog is a training tool that can enhance firefighters' understanding of single-family houses. The proposed typology of houses aims to make firefighters' occupational environment more intelligible and less "an undifferentiated collection" of houses.[186] Because vision is often severely limited in burning buildings, the house types would serve as mnemonic templates – as navigational aids – for wayfinding. The proposed catalog creates a scaffold to focus the brain's finite perceptual and cognitive resources on essential characteristics – on information the brain is hardwired to find – patterns and shapes. The catalog enables one to recognize and interpret rapidly and consistently, the essential patterns of cues associated with each of the house types.

To lessen the cognitive burden on the brain during fire suppression and search/rescue operations, firefighters should have access to a mnemonic – that is, a tool such as a standard set of patterns that will assist assessing each new burning house. The floor plan is at once a visual and tactile mnemonic (one that firefighters can feel in smoke) that leverages the spatial experience humans all have with houses (and other kinds of occupancies, for that matter) that can keep firefighters anchored in the present. The proposed catalog supports inferences, decision-making, information/knowledge transmission (i.e., storytelling), and current wayfinding practices by firefighters.[187] The next chapter examines the possibility of using standard house plan types as such a firefighting mnemonic.

Figure 4.10 Wayfinding in smoke requires a rapid assessment of the building on fire. John Odegard photo.

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CHAPTER FIVE

A Catalog of Floor Plan Types

> *"Architecture is to be regarded by us with the most serious thought. We may live without her, and worship without her, but we cannot remember without her."[1]*
>
> *– John Ruskin*

5.1 Introduction

Architecture comprises more than different configurations of structural members, material assemblies, and spaces. It is also a collection of memories, shared human experiences, knowledge, and stories with personal and collective meaning. How we perceive, remember, and speak about the built environment highlights how intertwined its existence is with our own. Marc Treib writes, in *Spatial Recall: Memory in Architecture and Landscape* that, "memory preys on places: there are virtually no un-situated recollections. Yet the mind exacts a price for preserving the past. Recollections are the fruit of conflict and compromise, indelible but unstable."[2] We often look to architecture for stability — to remember. Treib writes,

> Mnemonic values emerge from the difference between what I can and cannot recall. That the place has endured guaranteed its worth, in contrast to the disintegration of my memory. That is to say, mnemonic value derives from the fact that it has endured. Because it has endured, I can use the place to help me recall what I have forgotten. When we attribute mnemonic value to a place, we look upon it in a utilitarian fashion, in the sense that we regard the place merely as an instrument for us to achieve something else: a private recollection.[3]

Houses are a special type of architecture; essential places to one's individual and collective memory. The house serves an important mnemonic function structuring one's mental time-travel.

Their occupation allows firefighters access to thousands of buildings, including many houses. As a result, firefighters build up a storehouse of useful memories of past experience and knowledge, but this experience is affected by adverse working conditions, and it is unevenly documented. Because of this, their knowledge about buildings is not consistent. Firefighters rely heavily on memory of past experience to inform their decision-making under time-pressure and uncertainty. This can hamper decision-making and put firefighters, civilians, and structures at risk. There exists a need to lift this "equivocal knowledge out of the tacit, private, complex, random, and past to make it explicit, public, simpler, ordered, and relevant to the situation at hand."[4] The general inability of the fire service to recognize and effectively communicate environmental and spatial cues inhibits the use of underlying patterns of organization and construction that could provide a basis for better wayfinding practices. This does not mean firefighters know little, or are not able to communicate about houses, quite the contrary. Firefighters are very knowledgeable and communicate regularly about them, but this experience is often not articulated consistently, is often ambiguous in nature, and uses non-standardized, made-up terms. Firefighting practice lacks a jargon that considers the language of firefighting and architecture. Firefighters do not have a consistent and reproducible framework for assessing, interpreting, and naming houses. As a result, essential principles of spatial organization are "left poorly understood, marginalized, and predictably ignored."[5]

What firefighters need, but do not currently have, is a guide to structure their knowledge and experiences, a mnemonic tool to recognize, interpret, and communicate about houses. Such a guide, would describe standard house types, would allow firefighters to make more accurate inferences about the interior configuration of houses, based on their exterior massings, organization forms, patterns of fenestration, size, and arrangement of architectural details. Studying this guide and learning key house types would support firefighters' memory processes under the time-pressure and acute stress of the fireground. It would also better inform firefighters' wayfinding decision-making processes in unfamiliar environments. Firefighters regularly encounter houses that they have never been inside before. Understanding the floor plan before entering the house by knowing a "catalog" of standard types could reduce the number of variables for which a firefighter needs to account.

Chapter 5 proposes that firefighters can learn a number of house types (and their names), which are abstract representations of the most-common houses in the United States. As will be shown, these types can be identified early in the firefighting sequence – before entering a building on fire. They can help guide firefighters as they approach the house in the familiar firefighting sequence — from the *outside*, the *inside*, or from the *topside*. The proposed house types are based on architect and historian Thomas C. Hubka's extensive research as published in *Houses without Names: Architectural Nomenclature and the Classification of America's Common Houses,* with some additions. Hubka's research, of course, has drawn upon the work of other architectural historians in single-family houses, but Hubka's "prototypes" are the primary basis for the catalog proposed in this chapter. They present a stable foundation for inquiry that can help the firefighter make better rapid, *"educated guesses"* about the internal spatial organization (and other features) of a house on fire.

Chapter 5 examines an existing typology of houses through the lens of each type's spatial organization (e.g., how the rooms are configured to create varied interior spaces). In this document, the phrase "different house types" will refer primarily to the spatial organization of internal spaces, (i.e., the different floor plans of houses rather than, for example, their architectural style). Thus, the "mastery of ever more detailed classifications is not simply a matter of rote memorization, but a basis for understanding" how different types of houses influence firefighters' ability to wayfind in smoke.[6]

5.2 Relevant Historical Context

Methods of wayfinding, as documented by anthropologists and other researchers, vary widely, but there exists common ground among many examples cited in the literature. The Inuit, Anasazi, Polynesian navigators, and aboriginal Australian bushmen all had methods to *externalize* some of their context-specific knowledge to aid navigation. Each society used, or still uses, some form of external memory aid — wood coastline maps, stick maps, storytelling, verbal mnemonics, templates, and concise, descriptive language — all of which are useful representations of an environment.[7]

Part navigational aid and part mnemonic tool, physical representations such as maps or templates have always helped societies blend individual and collective experience. They also help reorient one's understanding of essential context to include not only space but also history and place, which can augment one's memory of the environment, aid recollection, and performance. These earlier navigational aids are often not highly specific about topographical details, and for good reason — they needed to be portable, easy to reference and use in the moment. They consolidate complex, often disparate environmental information and cues down to "fast facts." These examples provide a precedent for developing an external aid (a catalog of types) to serve a similar navigational and mnemonic function for firefighters today – in other words, to support wayfinding in smoke. Memory aids are important tools in wayfinding practice, particularly for people who might be navigating to or in places the person has not visited before.

5.3 Learning to Differentiate – Categories, Chunks, and Schema

According to Nobel Laureate and neuroscientist Eric R. Kandel in *Reductionism in Art and Brain Science*, "studies of learning and memory reveal that our brain has evolved highly specialized mechanisms for learning, for remembering what we have learned, and for drawing on those memories — our experience — as we interact with the world."[8] At the most basic level, the brain uses a reductive approach to separate the essential features of the environment from the non-essential in order to understand risk and make predictions, or "educated guesses." The brain processes everything by generalizing and classifying, but the brain cannot establish categories or make interpretations without memory.

In *Mind in Motion: How Action Shapes Thought* psychologist Barbara Tversky writes that "good categories sort most things into separate bins, not partially overlapping ones. The key to recognizing and categorizing things, objects is shape. Objects have shapes and the visual system is biased toward finding them."[9] For example, according to early-childhood educators, children start their education about the physical world by learning about is geometry. Learning about geometry helps children understand basic concepts such as size, shape, dimension, location, relative position, (a)symmetry, and direction. Geometry is also used to teach more complex concepts like identification, categorization, naming, pattern-recognition, spatial relationships, visualization, problem-solving, and spatial rules. Most importantly, geometry helps develop acute observational skills that help train the mind to identify and organize information quickly.

Geometry is one example of the sorts of categories that the mind is capable of creating. What this points to is that the mind organizes and shapes the continuous flow of sensory information into fundamental "units." Within brain science literature, these "units" are referred to as "*chunks,*" which are associations that help facilitate processing, storage, and retrieval of information in memory. The concept of a "chunk," as a kind of knowledge structure, was initially proposed in 1946, by Adriaan de Groot, a Dutch chess master and psychologist. It was described later by George A. Miller and again theorized by psychologists William Chase and Herbert Simon who studied memory in connection with skilled chess performance. Chase and Simon found that chess masters could rapidly process chess boards and engage in problem-solving using long-term knowledge structures known as "chunks." Chase and Simon's findings are extensively cited in literature on skilled (expert) performance. In "Chunking Mechanisms in Human Learning," cognitive scientist Fernand Gobet, et al., write, "recent work in perception, learning, and cognition has uncovered substantial evidence for a unifying information-processing mechanism known as 'chunking.'"[10] Gobet writes "each chunk collects a number of pieces of information from the environment into a single unit. The use of chunks explains how greater knowledge can lead to an increased ability to extract information from the environment, in spite of constant cognitive limitations."[11] Chess masters are the widely cited example, but there are others – including firefighters.

Successful wayfinding in smoke requires that firefighters be able to rapidly identify, interpret, problem-solve, and act on what they see (and feel). In order to do that, the brain encodes (and is able to retrieve from memory) an enormous amount of information organized in chunks (for example, the location and behavior of the fire, likely location of victims, etc.) Thinking beyond these chunks, firefighters are able to "rapidly encode a 'gestalt' of a scene which allows the extraction of a rapid understanding of the scene using global or statistical information."[12] This is possible in part because of the brain's ability to compress chunks of information hierarchically into more elaborate knowledge structures called *schema* that contain and organize sensory, perceptual, motor, experiential, spatial, problem-solving, and contextual information.[13] One can think of *chunks* as basic patterns, whereas *schema* are more elaborate patterns that encompass the essential context, the *who*, *what*, *where*, *when*, and *how* of a situation, and include a "retrieval structure," a memory trace alerting the brain to the content within the knowledge structure.[14] Schemas define the situations and settings where chunks can be used, the generalized patterns that underlie key chunks of information. In firefighting, as in expert chess play (and jazz music, for example), schemas are essential because they help enable anticipation, or "educated guesses," in real-time based on certain expectations. Knowledge structures like chunks and schema are extremely powerful perceptual and cognitive tools. They "reduce a wide variety of problems to a comparatively compact series of solutions," and allow "for a flexible rather than rigid rule-bound response to differing problems."[15] Schemas created by the brain (or accepted by the brain if the pattern is not created but learned) serve as mental organizers, retrieval cues, and, as proposed by this thesis, flexible *templates*, or models, supporting wayfinding practices of firefighters.

Before proceeding further, it is appropriate to define two terms. In the reviewed literature, various authors seem to conflate the terms *schema* and *template*. In "Five Seconds or Sixty? Presentation Time in Expert Memory," Fernand Gobet and Herbert A. Simon, define *schemas* as learned knowledge structures "with the specific intention of providing sets of 'slots' (variable places in which specific chunks of information can be stored rapidly."[16] Whereas *templates* "are schemas implicitly learned in the process of acquiring substantive knowledge, which also contain slots that can be used for rapid augmentation."[17] In an effort to acknowledge the distinction in brain science literature and existing terminology in firefighting practice, the terms *template* and *schema* can be considered interchangeable in this thesis. Further distinction between the two terms, while necessary and helpful in other fields of study, is not necessary here. In fact, the term "template" is likely to be understood without further explanation and is more likely to be accepted by firefighters, whereas "schema" would likely be met with some confusion or even derision as "too intellectual."

The catalog of house types can be thought of as a group of related wayfinding "templates." The house, as a template, has a "core, which is the non-variable part" and "slots, which constitute the variable part."[18] Firefighters are concerned with knowing the non-variable parts of houses – their "basic form, dimensions, patterns of fenestration, and general massing," and standard rooms and adjacencies (i.e., the spatial organization).[19] The walls, floors, and ceilings that create the invariant portions are fixed; although furniture may vary, certain furniture pieces are usually found in certain rooms (for example, beds and dressers in bedrooms). To a lesser extent, firefighters must also learn the variable parts. The catalog below is a conceptual and practical framework for learning about both. The floor plan types can be identified visually on arrival at a burning building. Identification of the type will alert firefighters to what they may expect to encounter visually – and when they cannot see, tactilely – inside a burning building.

The repetitive geometries of houses support recognition, classification, and interpretation quickly. In *Houses Without Names*, Hubka writes *that,* "generally speaking, creating categories by counting the number of similar things is a basic method for making sense out of a confusing universe and a basis for scientific classification."[20] This thesis advocates for the use of a typology of houses to establish the fundamental framework for improving wayfinding practices in residential fires. Alone, the geometry of houses – specifically their *forms* (the exterior shape), interior *configurations* (floor plans), and *patterns* of structural elements (that is, construction assemblies) are useful chunks of information, but combined with firefighting experience, the proposed catalog creates a set of open-ended wayfinding "templates" that have a familiar structure, facilitate memory processes, aid inferences, streamline communication, and encourage knowledge transfer.

In his essay "The Tell-The-Tale Detail," architect Marco Frascari states that geometry, "provides us with a structure for describing the built world, a conceptual framework into which the designer, the builder, and the user can fit their empirical experience."[21] Frascari says geometry "provides us with a linguistic or conceptual structure for the construction and the construing of a building."[22] Frascari's use of the word "construing" means to interpret. The "geometrical structures" Frascari writes about "give us a way of making comparisons that meaningfully relate visually perceived architectural details.[23] He is concerned with understanding architectural details, but his line of reasoning can be applied to understanding and communicating about the geometry of houses. For example, a working understanding of the principal concepts in geometry is key to being able to recognize, differentiate between, and name the basic types of houses. Geometry is a conceptual framework that can break down complexity inherent in the residential built environment into a number of templates that specifically emphasize common spatial configurations that firefighters need to be able to recognize and use to successfully wayfind in smoke.

The brain divides wholes into parts, and it is the parts of houses that give them their characteristic shapes. Any inquiry into houses should begin with that understanding. *Form*, *configuration,* and *pattern* constitute the syntax of houses – and they represent a framework for inquiry *before* the fire, *during* wayfinding tasks on the fireground, and *after* the fire, when speaking to one another about the experience. A typology of houses will support *rule-based* and *pattern-based decision-making* by firefighters – and *improvisation*, when required. The house types provided in this thesis are simple and flexible abstract representations of actual houses. The house types offer the firefighter chunks of information (i.e., geometry, familiarity with certain features of houses) and templates (schema) to organize this information which could prove helpful to firefighters asked to make rapid assessments.

5.4 Typology as a Way of Organizing Information

Classification is a central premise in the organization of information. Classification encourages the analysis of relationships between things, and "lies at the heart of many disciplines," including scientific inquiry, architecture, and firefighting.[24] For example, the built environment is often classified – by ***use*** (e.g., residential, commercial, educational, and institutional, etc…), by ***form*** (e.g., its shape, or "massing"), by ***construction*** (e.g., fire-resistive, non-combustible, etc…), and by ***style*** (e.g., Italianate, Stick, Queen Anne, Craftsman, etc…), among others. In architectural studies, the creation of typologies and the identification of types are "used to gather sets of similar buildings into manageable units for the purposes of study."[25] The principal methods architects, vernacular architecture historians, and other researchers use to understand buildings and to unravel their history, are the same ones firefighters need to identify the organizational principles of a building prior to wayfinding in smoke.

A *typology* can be thought of as the systematic study and interpretation of types.[26] It is a method of understanding things through classification. Two specific typologies represent common ground between firefighters and architects. First, a *typology of structural arrangements* (e.g., types of frames – timber, balloon, or platform; and types of assemblies – Type I: fire-resistive, Type II: non-combustible, Type III: ordinary, Type IV: heavy-timber, Type V: wood frame). These common typologies serve as a method of organizing information that helps both disciplines identify patterns of void spaces, paths of fire travel, and the potential for structural collapse during fire. Second, a *typology of spatial organization* (e.g., the arrangement of rooms into specific sequences and how those different configurations shape the interior spaces and subsequently the exterior shape of a building). There is an underlying geometric order – a rational organization – behind the way types of buildings have been (and continue to be) used, shaped, constructed, and ornamented. This thesis is focused specifically on a typology of spatial organization in different types of houses.

A *type* as defined by the *Oxford English Dictionary* is "the general form, structure, or character distinguishing a particular kind, group, or class of objects."[27] As its etymology suggests, a type "(from the Greek *typos,* an impression, a cast, a model) has recurrent, general, distinctive features."[28] Marc Treib adds additional architectural context in *Spatial Recall: Memory in Architecture and Landscape* when he writes,

> The type is what survives when the overlay of styles is stripped away to reveal the basic form, dimensions, patterns of fenestration, and general massing of particular kinds of buildings. Types codify the know-how handed down through generations in terms of customs, social and economic history, building trades, or climate. They persist stubbornly when all else changes, withstand war and insurgency, economic recession and fashion, and the successive avatars visited upon all cities, and constitute a form of urban memory that transmits knowledge about the interaction of architecture and society in specific places.[29]

If ornament is removed, what remains are easily recognizable parts and essential histories of the building. Stewart Brand writes in *How Buildings Learn: What Happens After They're Built* that, "architectural history, because it came from art history, has tended to focus on style."[30] Style can be misleading and is generally unhelpful to firefighters. Classification by construction type, another common typology extensively cited by firefighters, is also highly problematic. For most buildings, it is difficult to identify construction type from the exterior without detailed knowledge about its design (i.e., from blueprints or a visual inspection of structural elements hidden within a construction assembly). Brand is writing here about dating buildings saying that the best way to uncover their history "is to look at things that are the least likely to lie to you – essentially, the things that are least self-conscious."[31] Firefighters too need a metric that helps to orient them to stable features of the built environment. For the purposes of wayfinding within the time frame of a fire, the floor plan serves this purpose well.

5.5 Establishing Performance Objectives of the Types

In order to be useful to firefighters in their primary work environment, five specific performance objectives must be met by the catalog:

> ***First***, the types must be simple to understand, facilitate rapid recognition, be easy to recall, and be helpful *before*, *during* (to a limited extent), and *after* firefighting operations.
>
> ***Second***, the types must convey information applicable to the different sequences of fireground operations – *Outside, Inside, and Topside*. They must apply to the fireground rituals enacted by engine and ladder company firefighters and chief officers.
>
> ***Third****,* the types must establish a clear, easy to identify typology (categorization) of houses. The catalog of types should reduce the enormous numbers of different houses to a more manageable number of types to learn.
>
> ***Fourth***, the names of the types must use simple, precise language. It is necessary that the types have descriptive names that conjure an accurate picture in mind.
>
> ***Fifth***, the catalog should allow for expansion if one identifies additional dominant local variations.

The primary scholar of house identification by plan types, Thomas C. Hubka, advocates for, "a two-part identification formula" one that is "a combination of outside and inside labeling. Typically, this couplet would link a term interpreting exterior style or form with a term interpreting floor plan or room usage."[32] This is the approach taken in this thesis. The names of the house types are descriptive and precise. Currently, firefighters have no standardized way to refer to types of houses.

5.6 Rule of Dominant Types

This thesis will only examine the detached residential dwelling and considers it in the context of wayfinding in smoke. (All configurations of houses could be studied using the framework outlined in this thesis to create typological catalogs for firefighters. However, as this is a new idea to firefighting, this thesis specifically addresses the numerically largest group of buildings firefighters encounter, single-family houses which are generally detached dwellings). For example, according to the 2021 National Fire Protection Association (NFPA) Home Structure Fires report,

> More than one-quarter of the reported fires in 2015–2019 (26 percent) occurred in home environments. In addition, three-quarters of the civilian fire deaths (75 percent) and almost three-quarters of the reported civilian fire injuries (72 percent) during that time period were caused by home structure fires. During this five-year period, US fire departments responded to an estimated average of 346,800 home structure fires per year. These fires caused an annual average of 2,620 civilian deaths; 11,070 civilian fire injuries; and $7.3 billion in direct property damage. Of the reported home fires in 2015–2019, 69 percent occurred in one- or two- family homes, including manufactured homes. These fires caused 85 percent of the home fire deaths, 65 percent of the home fire injuries, and 79 percent of the direct property damage.[33]

Hubka examined the underlying unity of popular house plans by using an method he refers to as the "rule of dominant types."[34] This rule defines how "a majority of local builders, both currently and in previous periods, have narrowed the always wide range of potentially available houses into a more limited range of well-known, frequently repeated, locally accepted types."[35] His method of identification and classification, "differs from standard scientific taxonomy, for example in the biological sciences where the identification of different species, not the counting of individual members of each species, is the primary concern. Here, the counting of the largest numbers of particular house species becomes the dominant criterion for classification."[36] Hubka writes, "this concentrated uniformity of a few dominant house-plan types out of an always much larger variety of national and regional types is a consistent, fundamental rule of common-house development in all periods and regions."[37] Following Hubka's "prototype" examples, this thesis will advocate that firefighters adopt a two-part classification system for houses — classifying them by "internal (plan) and external (form) characteristics."[38]

Applying this method of inquiry to houses in any location will allow firefighters to establish a decision-making approach (almost an "algorithm") based on common house types, in their specific geographic area of responsibility (also known as "response area"). The expectation that a house conform strictly to a specific type is not absolute. Firefighters encounter hoarding conditions, grow operations, un-permitted renovations, comprehensive modifications, and odd houses all the time. Given that wood is a material that is easy to manipulate, even amateur builders can modify a house. Records of these changes, if they exist, are sometimes not evident in the shapes of the structure and in the voids created by construction assemblies. In other cases, changes are obvious. Over time, patterns have developed that outline the history, construction assembly, evidence of alterations, and probable paths of fire travel. Without a framework to make sense of these changes, there is only chaos. Using an understanding of house types to help fight fires focuses on properties they share, not on occasional differences.[39] The catalog works from "probability to possibility."[40] Firefighters starting from the basic, "most-probable" types can then report variations encountered on the fireground. The basic types give firefighters not only a common language to share information, but also a starting point for describing variant plan features when they are encountered.

5.7 Toward a Minimum Standard House

Over time, various types of houses were created in response to in local and national tastes, financial and cultural influences, and technological advancements. Hubka writes that one can trace the history of these changes because there are, "three basic patterns of room usage and domestic function that underlie the historic development of domestic space and domesticity within common American houses: (1) kitchen-centered to multi-centered living; (2) increased room size, number, and differentiation of rooms by usage; (3) increased acquisition of technologies, utilities, and household amenities."[41] Over time, a minimum standard was developed; house forms were codified to include five standard rooms: *living room*, *dining room*, *kitchen*, *bedroom*, and *bathroom* — the fundamental "units" of houses. Today, most houses have these rooms in common (at minimum). One can also make an argument to include the *garage* as part of today's minimum standard. Most houses will have additional rooms beyond the minimum standard — for example, more bedrooms and bathrooms, an office, laundry room, and so forth. Additionally, some house types will combine room functions (for example, a combined living-dining room). Although periods of prosperity have dramatically increased house sizes to an average of "2,200 square feet, up from 980 square feet in 1950 and 1,500 square feet in 1970," larger houses still feature similar plan types.[42]

At the same time, houses designed since the early 1900s, have ***public*** and ***private spaces*** which organize the "units" into defined configurations and sequences of experience. For example, the living and dining rooms are generally the more public; the bedrooms are generally private. In some areas of the United States, the topography shapes house form to a much greater extent than other areas. Seattle, San Francisco, and Pittsburgh are illustrative examples. In these locales, public and private spaces can be inverted to take advantage of views of the landscape. Regardless of size, era, or topography, a house is made up of "units," or rooms. Every house is basically a collection of these "units." Most houses are made up of standard sets of units grouped together into different configurations and some configurations are more probable than others. For example: a house can be configured two rooms (units) wide, and two deep. Or two rooms wide, and three deep, and so forth. Much of this can be "picked up" or read, from the exterior by looking at exterior cues such as: exterior massing, patterns of fenestration, size, soil pipes, arrangement of architectural details, position on the site, and overall shape, among many others. Every cue is associated with an expectation. What firefighters are trying to do is rapidly locate a number of cues to confirm spatial organization of the house before entering.

5.8 Exterior Form

The geometry of houses – specifically the ***forms*** (the exterior shape), its relationship to interior ***configurations*** (floor plans), and the ***patterns*** of structural elements (that is, construction assemblies) together make up a template that orients firefighters to the likely plan, unique features, history, and how one might address fire spread and search/rescue inside. Additionally, a house's estimated era of construction, dimensions, the patterns of fenestration, and general massing can become heuristics firefighters use to make tactical decisions, and "educated guesses."[43] A heuristic is essentially a "rule of thumb."[44] The fact that the floor plan types are abstractions of real houses whose shapes are noticeably different from one another, will specifically enable firefighters to make rapid assessments based on their *position* (outside, inside, topside) or the *task* they are assigned (e.g., fire suppression, search/rescue, or incident command). With some practice, a firefighter can "rapidly extract global information" about the house "which can be used to guide their subsequent search" of the inside of the house.[45]

The following catalog of types represents the national antecedents of local house types throughout the United States (thus, it applies here in Seattle, where this thesis was written, and elsewhere). Most response areas only have 4-6 (or fewer) of the plan types – and these represent a baseline expectation. Learning to identify the most common of these types (and local variations) can be an important enhancement to firefighters' ability to wayfind in smoke. Not only does it improve their understanding of common houses, but knowing the baseline makes the anomaly easier to identify and communicate. While houses that are exceptional cases may warrant little extra study, at least initially, knowing that a house does not conform to one of the common types is useful (potentially lifesaving) information.

Firefighters make rapid, *"educated guesses"* about a house that is on fire. They make educated guesses about the location of fire, possible victim locations, paths of travel, areas of refuge, and so on. Firefighters will not have time to thoroughly identify the house type in an architectural sense; they must instead identify the "gist" of the house, particularly the general configuration of the rooms in it. What the catalog of types does is cue the brain to look in the "correct bin" for memories associated with a type of house on fire, for a particular *pattern*. In smoke, the brain relies primarily on information derived from somatosensory inputs and from memory, rather than from vision. On the fireground it also must rely on partial information about a house's interior overlaid with a confusing volume of other information. The types help structure (and to an extent, constrains) the brain's search for information. The types support more effective wayfinding in smoke.

5.9 A Catalog of Floor Plan Types

While valuable to architectural historians (and to preservationists surveying the built environment), in this thesis this classification system serves as a framework that firefighters can use to quickly recognize, recall, and communicate spatial characteristics of the houses they regularly fight fires in. The floor plan types serve as templates for wayfinding. Such templates do not currently exist in the fire service. Firefighters, who encounter houses frequently, are expected to quickly "pick-up" the relationship between the house exterior they see when they arrive at a burning residence and the configuration of spaces (the floor plan type) they can expect to encounter inside (when smoke will limit detection of visual cues). The relatively stable patterns of occupancy use, interior configuration, materiality, structure, and construction assembly of houses, create external memory aids, as this thesis has argued. Firefighters, however, receive little training in what to look for.

The catalog provides a simple framework organized into different types of houses for the specific purpose of helping firefighters orient to specific features. The catalog makes the most common types of houses recognizable and intelligible to firefighters, regardless of their level of experience or training. Following Hubka's examples, this thesis will advocate for using his two-part classification system for houses — classifying by "internal (plan) and external (form) characteristics."[51] A house's "basic form, dimensions, patterns of fenestration, and general massing,"[52] can all be identified, with some practice. This information can be translated quickly into cues firefighters can use to find their way in its smoke-filled interior.

Within the sequence of emergency operations, there is only enough time for "good-enough" decisions. These are made by (1) knowing what to look for, (2) knowing when enough information is enough (the "threshold of decision"), and (3) knowing what decision to make.[53] Using heuristics focuses one's attention on the important cue (or cues) and helps one ignore distracting information. They separate from the unending stream of information the essential from the non-essential. In this thesis, the heuristics are concerned with wayfinding which involves recognizing the floor plan of houses. The essential purpose of the catalog of house types is to identify how the external (form) characteristics are shaped by the internal (floor plan) configuration of rooms.

In "From the Recognition Primed Decision Model to Training" researchers Karol G. Ross, James W. Lussier, and Gary Klein, write "expert performance is based on extensive knowledge that is 'indexed.' Indexing consists of facts and relationships being linked in terms of *cues*, *expectancies*, *goals*, and *typical actions*:

> **Cues** – If I see this, it means a larger pattern probably exists in the situation.
>
> **Expectancies** – In that pattern, I've usually seen things unfold in this way.
>
> **Goals** – It is important in this type of situation to do this.
>
> **Typical actions** – I have seen this goal achieved by doing the following.[54]

The catalog proceeds from the premise that firefighters need to think about what *cues*, *expectancies*, *goals*, and *typical actions* are associated with wayfinding tasks in each type of house. The following heuristics outline important things to consider when looking at houses to identify the floor plan prior to wayfinding:

1. Identifying *where* one will enter the house is a critical first step. Engine companies enter the building most-often through the front door. Ladder companies, however, must be cognizant of the fact that they may enter the house from the front door, but could also enter from a different door or through a window, if performing a window-based search. The entrance changes the sequence of rooms the firefighter will encounter.

2. Identifying the configuration of the living room, dining room, and kitchen is the next initial "guess" firefighters need to make regarding the floor plan; by identifying this triplet, the firefighter is also oriented to possible locations of bedrooms and stairs up and down. To forecast where the rooms in this triplet are, certain cues can be

helpful. For example, in older houses, a chimney on an exterior wall often indicates the living room. In houses built after World War II, the garage is generally integrated into the shape of the house. The garage is usually connected to (or located adjacent to) the kitchen.

3. Stairs can be located in three places: *obvious from the front door* (centrally located or off to one side), *located in a hallway adjacent to bedrooms* (often accessed through the dining room), or *located in or adjacent to the kitchen* (some house types will have a separate service staircase). Stairs down to a basement are often under the main staircase or in a separate location like the kitchen in houses built before refrigeration. In those cases, the house is likely to have an exterior staircase indicating the location. Additionally, window location and size can alert the firefighter to the presence of a staircase; so too can the pitch of the roof. Stairs need room, so as a result, in a number of house types, the rise of the staircase will follow the pitch of the roof.

4. Floor plans can be inverted in certain house types meaning private space (bedrooms) are often found on the entry level, and one must go up the stairs, in order to access the public spaces (living room, dining room, and kitchen).

5. Certain house types move the kitchen to the front of the house, closer to the front door. This is common in houses that were designed to take advantage of a view to the landscape.

Note: This is not a comprehensive list, just an illustrative example of some valuable heuristics.

Accurate heuristics are developed and modified through observation, practice, repetition, and open dialogue. Visual expertise of the sort firefighting requires, necessitates that one spend time looking at houses – lots of them. In order to make accurate assessments of a building during firefighting operations, firefighters need to practice their assessments beforehand. It is often said that "small details reveal big things."[55] This is especially true during emergency incidents, such as fires. Herman writes, "to gather data successfully from what we observe, we cannot assume anything."[56] Looking closely is the only way to be aware of these details. Each job on the fireground has a routine that shapes what one looks for and ultimately what one "sees." By practicing the separate visual inquiry routines, one trains the brain to make judgments about incoming sensory information. Looking at houses using the catalog of types as a field guide is a good place to start developing this skill.

This classification system is based on identifying distinctive "internal (floor plan) and external (form) characteristics" of each individual type. According to Hubka, classification in this manner has five advantages:[57]

1. Floor plans create distinct, verifiable, and quantifiable types.
2. Every house has a floor plan. No house is excluded because of its architectural treatment.
3. The floor plan underlies how most people understand, remember, and talk about houses.
4. The floor plan can be interpreted from the exterior, in most cases.
5. Every house type has a descriptive name that prompts an image in mind.

According to architect Christine Hunter, the residential built environment can be divided into three configurations, or arrangements: freestanding houses, rowhouses/townhouses, and apartments (see Figure 5.1).[58] She writes "because of minimum building code requirements and standardized methods of construction, the sheltered spaces, or rooms, inside these three types of homes are now quite similar."[59] This the catalog is concerned with this similarity.

Detached dwellings (freestanding houses) – Which have land on all sides. This type of house is the primary unit of most urban and suburban neighborhoods.

Attached dwellings (rowhouses/townhouses) – Attached dwellings are created "when the exterior walls of two buildings touch along a property line, or when they actually share a wall, then they can no longer be clearly seen as distinct objects."[60] Hunter writes that "while houses can connect to one another in a number of geometric patterns or in a random assemblage, the form of attached house most common in this country is generally known as a rowhouse or townhouse."[61] Hunter writes that, "at their most basic, they are simple rectangles in plan, with common or contiguous walls on two opposite sides."[62]

Attached and stacked dwellings (apartments)[63] – The apartment is a grouping of individual units (configured adjacent to one another with units above/below) within a single building. An apartment building "requires the creation of semipublic spaces for entry and circulation."[64] Units can be accessed by stairs and/or elevators. According to Hunter, "apartment houses come in a wider range of forms and sizes than do single-family dwellings."[65] Far fewer interior configurations exist, however.

Hunter's abstraction represents a simplification of the most-popular arrangements of houses that is useful to firefighters. These can be identified with little to no training because it makes intuitive sense.

Regardless of background, one is always, to some degree or another, aware of certain spatial configurations common to various house types. People spend a majority of their lives inside residences (of all types). Residents remember the pattern of their own home as spatial features are burned into the circuitry of the brain. In fact, each person can be considered an expert about certain kinds of houses, having come, through repeated experience, to (unconsciously) know the nuances of these types. The catalog of types of houses gives firefighters a common frame of reference — a frame beyond idiosyncratic personal experience. Additionally, the catalog relates firefighting experience and knowledge to quantifiable housing data. It advocates for a type of holistic visual processing that rapidly extracts global information about the house on fire from the outside, which is then used to inform a subsequent search inside in toxic smoke — for people and fire.

Firefighters must orient to and navigate within a house they may have never seen before, and they must do this very quickly. The catalog of types provides a way to "pre-process" (and "post-process") spatial information they will need to find to make decisions during acute stress. Typologies and hierarchies like those created by Christine Hunter, Thomas C. Hubka, among others, reduce the amount of sensory information that must be processed by the brain. The house types proposed in this chapter are a framework for the brain's default hypothesis testing operation. They tell the mind *what* to look for and *where* to find information as it makes predictions about the environment. This thesis focuses specifically on how the detached dwelling and its associated patterns of cues impact firefighters' ability to wayfind when it is on fire.

Figure 5.1 The three arrangements of houses.[66]

THE CATALOG OF HOUSE TYPES

Within the proposed catalog, there are 16 types. Hubka in *Houses Without Names*, presents 14 "prototypes," and their common variations. This thesis proposes the addition of two additional "prototypes" specific to Seattle, Washington, although they may appear in other areas of the country as well. The two additions are the result of Seattle's topography and proximity to water. There may be others.

Each of the prototypes include a floor plan and pair of possible elevation drawings. Each type includes the associated drawings for a notable variation. Some house types include multiple variations. Occasionally houses may be found that are not illustrated in the catalog, but experience shows these to be relatively rare.[67] There is likely to be local variations of the prototypes not illustrated in the catalog. After introducing the 16 "prototypes," the reader will be shown an illustrative example of how firefighters could analyze each of the "prototypes," and associated variations. This catalog extends firefighters' individual knowledge, by drawing on the collective knowledge of American house types — and other firefighters' experience.

One can begin analyzing the types by separating them into three basic exterior forms, ***"wider-than-deep"*** (with long axis parallel to street), ***"deeper-than-wide"*** (with long axis perpendicular to street), and ***"square."***[68] In many cases, a house is a combination of multiple forms. House forms have been codified to include five standard rooms: living room, dining room, kitchen, bedroom, and bathroom – the fundamental "units" of houses (see Figure 5.2). Today, most houses have these rooms in common (at minimum). Quickly examining the exterior form of the house (i.e., how *wide vs. how deep)* proves to be very helpful in determining how many rooms in each direction the house contains. The critical next step in interpreting the house is to determine (to the extent possible) the *kitchen*, *dining-room*, *living-room* configuration.

Some houses are easy to identify, others are not. With a little practice, however, identifying houses beyond superficial classifications such as shape or style, can advance to more sophisticated identification that utilizes a combination of cues such as: massing, number of stories, door location and swing, window size, shape, and pattern; chimney location, soil pipe location, decoration, era, and so on. One can make ever finer, more accurate distinctions, by understanding how the catalog establishes a baseline conditions for each type. It can be thought of as a framework for further inquiry**.**

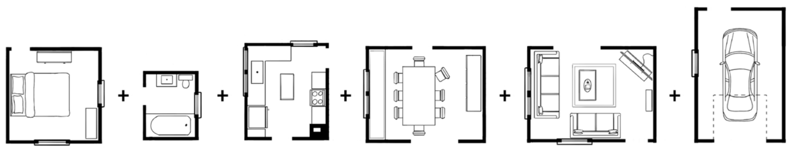


Figure 5.2 The minimum standard rooms.

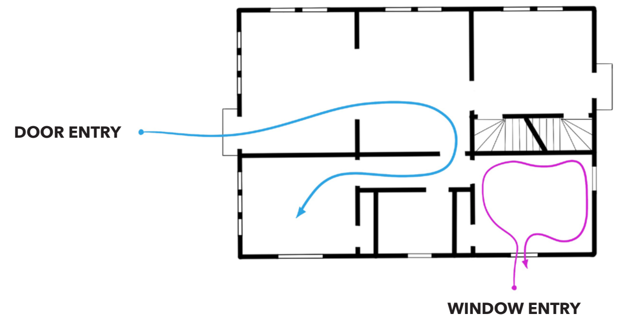


Figure 5.3 Paths and places.

The types can be simplified further by translating the spatial configurations, (i.e., the geometry) of each type of house into a spatial mental model of *paths* and *places* (or rooms or "compartments," in firefighting jargon) and the relationship between the two (see Figure 5.3)[69] Firefighters are concerned with being able to quickly identify spatial configurations because it influences how they wayfind in smoke. Firefighters internalize the floor plan, reducing a three-dimensional environment down to a two-dimensional representation. Generally, firefighters enter the house on fire either through a door or window to perform a search. Regardless of assignment, firefighters need to know *what* path to take *where*. Considering house types in terms of their "paths and places" simplifies the spatial mental model in an effort to reduce the cognitive demand.

Houses are composed of distinct spatial configurations, as illustrated by the plan types. Firefighters experience these spatial configurations as organized networks of interconnected places. As Ruth Conroy Dalton explains, "any set of spaces, of sufficient complexity to be described as a configuration, tends to form a spatial hierarchy in which some spaces become more strategic and others less so."[70] For example, interior residential spatial configurations have been shown to follow a distinct pattern, specifically in the linkage between the kitchen, dining, and living rooms. In certain types of houses paths are clearly articulated as hallways (for example, the split-entry house); in others, rooms are connected without clearly defined paths (for example, the bungalow or many modern open-concept houses). The paths firefighters are able take are dictated by the fire conditions present on arrival, the type of house, how the house is furnished, and what entrance they use (door vs. window). Therefore, when studying the catalog, firefighters would do well to simulate various fire locations and the paths required to reach them — and do it from the engine and ladder perspective. Architects and historians have studied the repetitive character of housing. Firefighters have not, to any real extent. House types reflect a variety of local and national tastes and constraints, financial influences, and technological advancements. The standardization of residential dwellings has been the result of craft practice, experimentation, empirical knowledge, and a process of industrial optimization. The recognition of the underlying unity of houses across different eras can provide firefighters a basis for more effective decision-making in smoke. In "Getting Lost in Buildings" human spatial navigation expert and psychologist Laura A. Carlson and others write,

> There is a taxonomy of features for wayfinding in a building that includes (a) visual access between key locations, or the degree to which one can see other parts of the building from a given location; (b) architectural differentiation, or the degree to which different parts of an environment appear unique or might be confused; and (c) layout complexity, or the number of rooms and corridors and their configuration.[71]

When houses are classified by types, each with discrete organizational (or spatial) characteristics, there is stability, but also adaptability which is crucial for firefighters in situations that deal with time-pressure, uncertainty, and visual impairment.

Firefighters, asked to wayfind in smoke inside an unfamiliar house require the ability to rapidly gather spatial knowledge from its exterior. In addition to other skills (discussed in earlier chapters), wayfinding in this environment requires mental simulation (i.e., imagination). Place names are proven helpful for orienting one to a specific place and with conjuring an accurate image of the place in mind. Researchers who study toponyms have pointed out that wayfinding know-how is often tied to the name of a place, landmark, feature, or phenomena. According to anthropologist Ludger Müller-Wille in "Place Names, Territoriality and Sovereignty: Inuit Perception of Space in Nunavik (Canadian Eastern Arctic)" place name systems,

> Have differentiated the environment using proper names identifying specific qualities of places. In oral traditions, the place name systems serve as mental maps which consist of indispensable and crucial signposts and markers organizing and qualifying the resources in the physical and cultural landscape.[72]

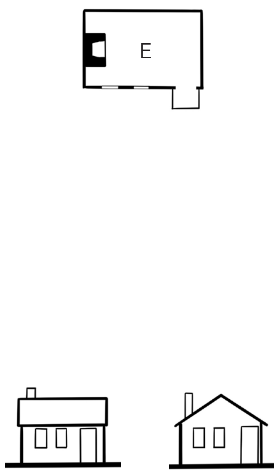
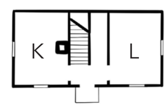
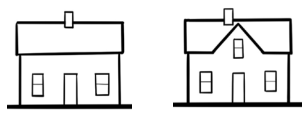
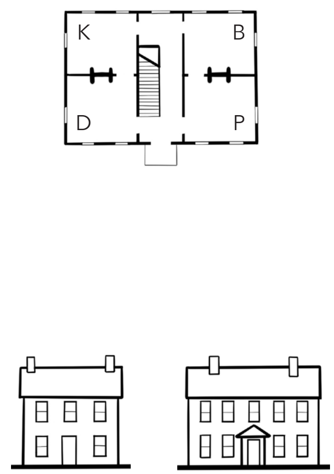
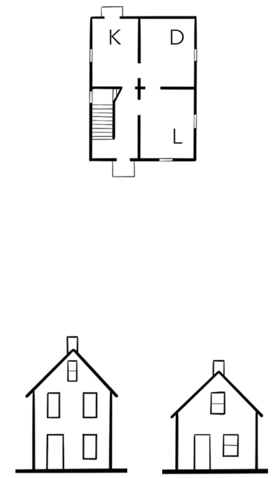
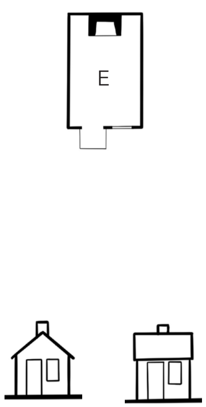
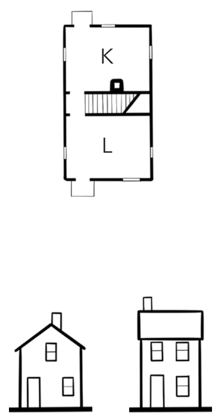
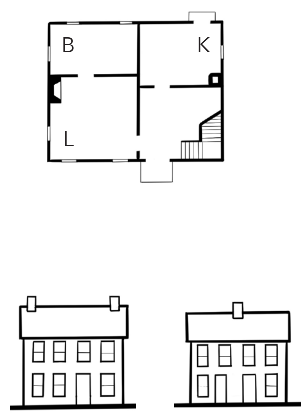
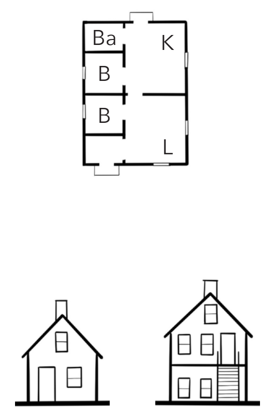
Place names "contain a large scope of information: geographic orientation and distance; environmental conditions; location, accessibility and availability of resources; historical information, cultural knowledge and heritage."[73] Current practices in house naming are haphazard, confusing, unhelpful to firefighters asked to wayfind in smoke. Architect and historian Hubka in *Houses Without Names* writes, "when viewed as a whole, the current names for common houses reveal the confusing, non-hierarchical, non-historical nature of the interpretative process."[74] It is clear that naming is essential to interpretation — for anthropologists, historians studying houses, and for firefighters tasked with wayfinding in smoke. A typology of houses (i.e., the catalog, Tables 5.5 - 5.10) with highly descriptive names provides firefighters with a way to organize spatial information, facts, past experience, cultural expectations, history, create inferences, and ultimately become a tool for orientation and navigation inside a burning building.

The time-sensitive nature of a fire event requires that firefighters be able to communicate quickly, clearly, and effectively with one another. This is especially important for firefighters operating inside the burning house who must communicate fire and smoke conditions, along with one's location within the structure to command officers outside. The floor plan types offer firefighters a shared point of reference. It allows for a consistent image to be conjured in mind, and attaches descriptive names to houses facilitate the conveyance of wayfinding information. The first essential step in learning to distinguish between house types and wayfind in smoke, is to learn to recognize and name of the most-common types.

PRE-MODERN	ONE-ROOM PLAN	
	TWO-ROOM PLAN	
	TWO-ROOM-DEEP PLAN	
	SIDE-HALL PLAN	
TRANSITIONAL	SIDE-GABLE PLAN	
	PARLOR BY-BASS PLAN	
	VICTORIAN HOUSE PLAN	
EARLY MODERN	FOUR-SQUARE PLAN	
	BUNGALOW PLAN	
	PERIOD REVIVAL PLAN	
MODERN	RANCH PLAN	
	SPLIT-LEVEL PLAN	
	SUBURBAN MINIMAL TRADITIONAL PLAN	
	MANUFACTURED PLAN	
	HOUSEBOAT PLAN	SEATTLE SPECIFIC
	"SKINNY" HOUSE PLAN	SEATTLE SPECIFIC

Table 5.4 Hubka and Legan House prototypes.[75]

Table 5.5 – PRE-MODERN PROTOTYPES (1800-1900)[76]

ONE-ROOM PLAN TYPES	TWO-ROOM PLAN TYPES	TWO-ROOM-DEEP PLAN TYPES	SIDE-HALL PLAN TYPES
Pre-1800 - 1860+	Pre-1800 - 1900	Pre-1800 - 1860	Pre-1800 - 1900
Aka: "Single-cell" or "Tiny house"	*Aka: "I-House" or "Single-Pile"*	*Aka: "Georgian Plan" or "Double-Pile"*	*Aka: "Rowhouse plan"*
One-Room (Side Entry)	**Center Passage**	**Central Passage**	**Side-Hall**
	 *Note: The southern "Shotgun" house type could be included here.* 		
One-Room (Short-End Entry)	**Rowhouse Type**	**Germanic Traditions**	**Worker's Cottage**
			

Jordan C. Legan illustration. Reproduced from Hubka's *Houses Without Names, 53-54.*

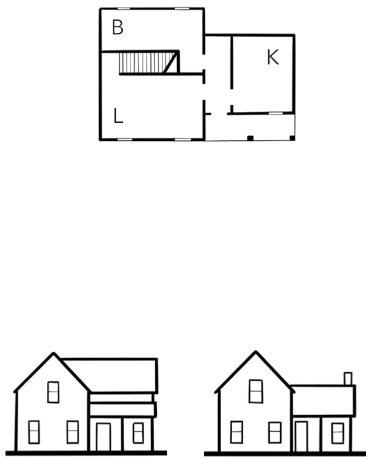
Table 5.6 – TRANSITIONAL PROTOTYPES (1820-1900)[77]

SIDE-GABLE PLAN TYPES

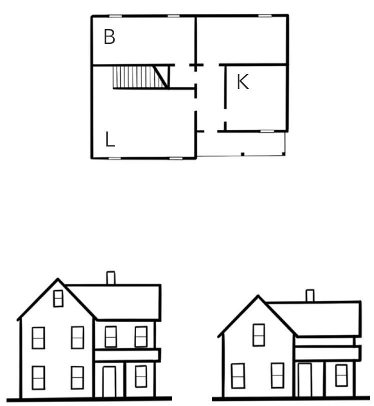
1800 - 1900

Aka: "T-Plan" or "Upright-and-Wing"

Side-Gable



Expanded Side-Gable

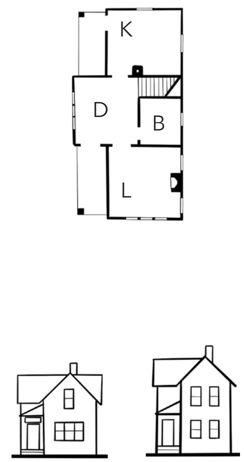


PARLOR BY-PASS PLAN TYPES

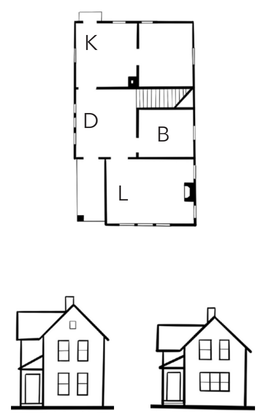
1880-1910

Aka: "Side-Porch Plan"

Parlor By-Pass



Expanded Parlor By-Pass

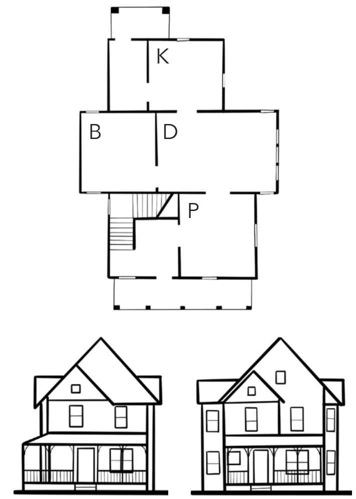


VICTORIAN HOUSE PLAN TYPES

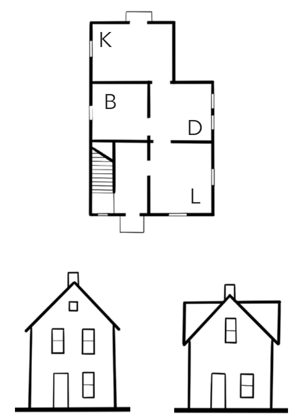
1850-1920

Aka: "Queen Anne"

Victorian House



Expanded Side-Hall



Jordan C. Legan illustration. Reproduced from Hubka's *Houses Without Names, 55-56.*

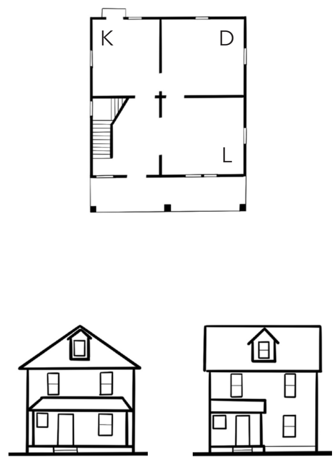
Table 5.7 – EARLY MODERN PROTOTYPES (1860-1980)[78]

FOUR-SQUARE PLAN TYPES

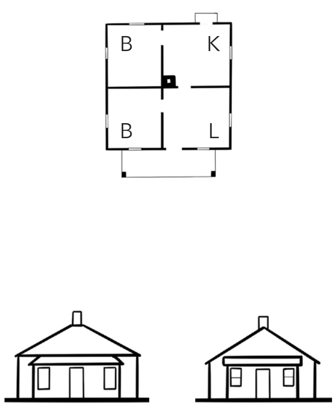
1860 - 1920 [1930]

Aka: "Four-Box" or "Seattle Box"

Four-Square



Four-Box

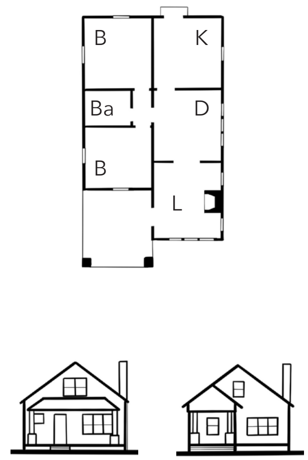


BUNGALOW PLAN TYPES

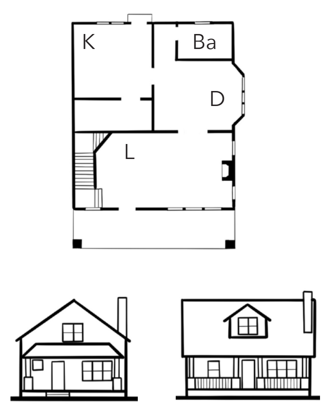
1900-1930

Aka: "Craftsman Bungalow"

Standard Bungalow



Large Bungalow

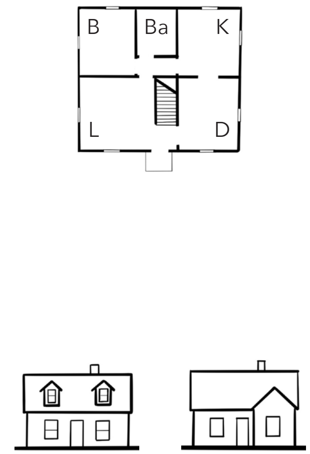


PERIOD REVIVAL PLAN TYPES

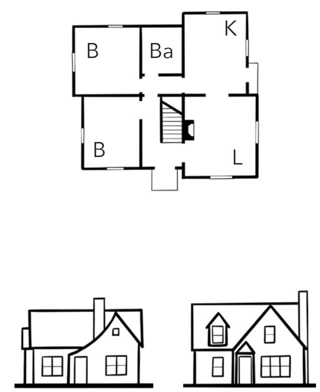
1920-1980

Aka: "Cape Cod" or "Tudor"

Minimal Traditional

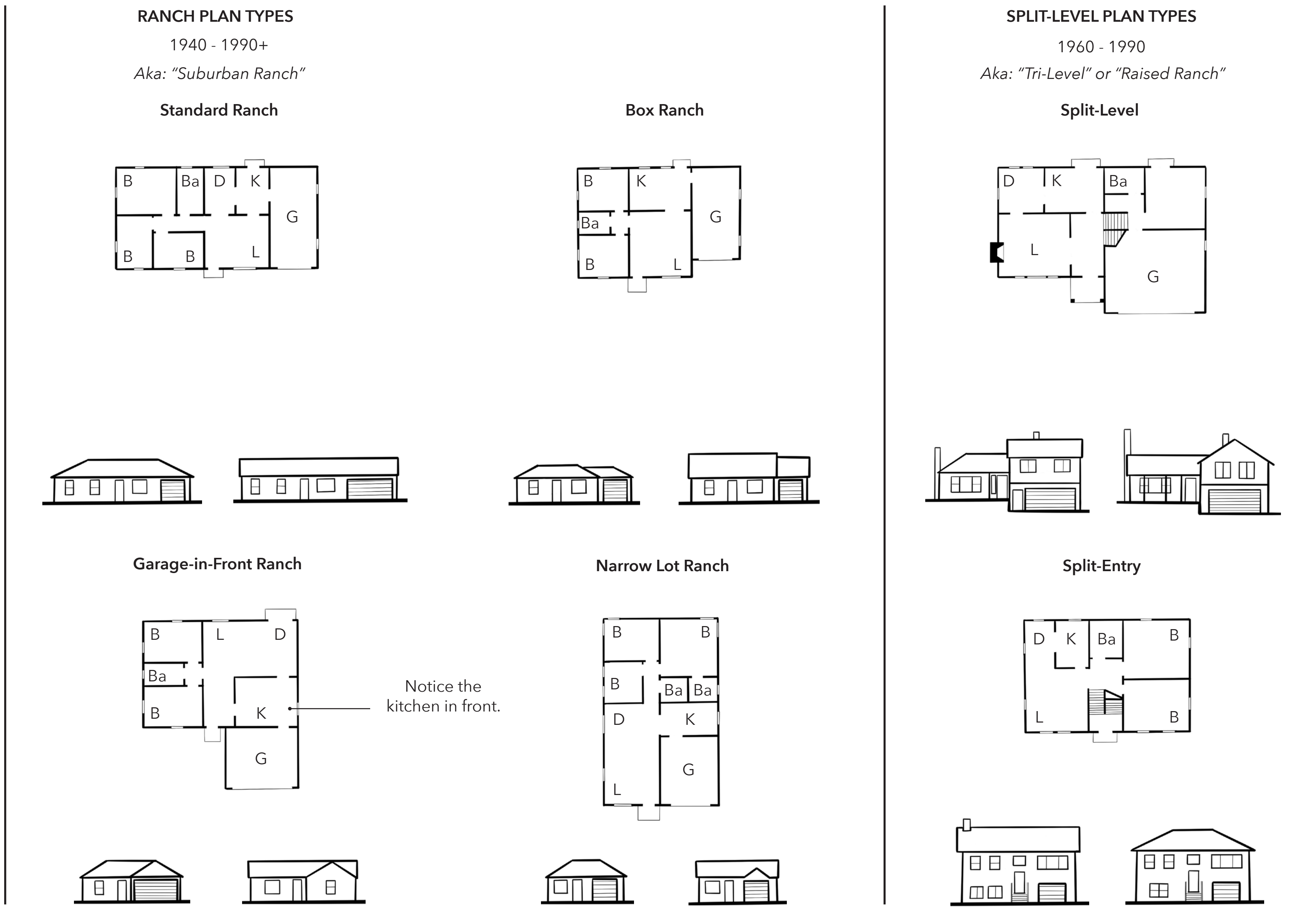


Period Revival



Jordan C. Legan illustration. Reproduced from Hubka's *Houses Without Names, 57-58.*

Table 5.8 – MODERN PROTOTYPES (1940-2000)[79]



Jordan C. Legan illustration. Reproduced from Hubka's *Houses Without Names, 59-60.*

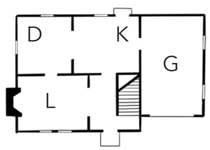
Table 5.9 – MODERN PROTOTYPES (1940-2000) CONTINUED[80]

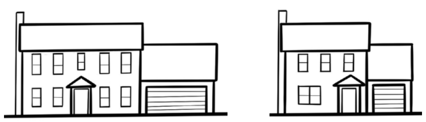
SUBURBAN MINIMAL-TRADITIONAL PLAN TYPES

1950 - 2000+

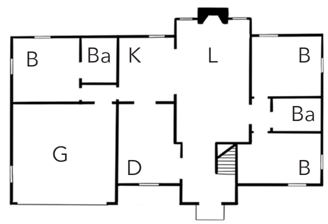
Aka: "Colonial Revival" or "Developer Housing"

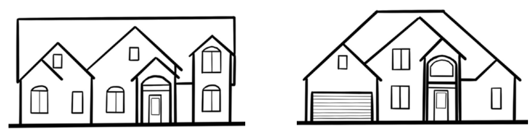
Traditional/Revival



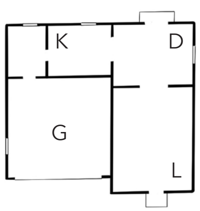


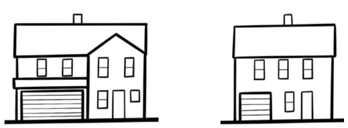
McMansion



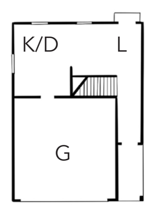


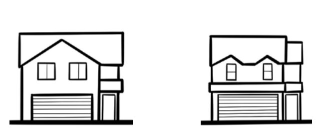
Suburban/Developer





Narrow-Lot Suburban



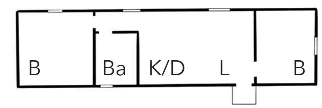


MANUFACTURED HOME PLAN TYPES

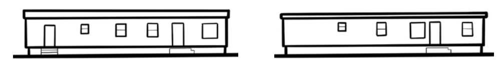
1930 - 2000+

Aka: "Mobile-Home"

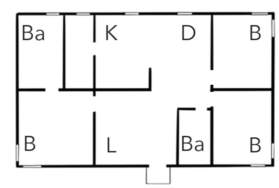
Single-Wide



(Plan varies widely)



Double-Wide



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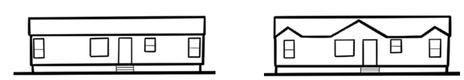


Jordan C. Legan illustration. Reproduced from Hubka's *Houses Without Names, 61*.

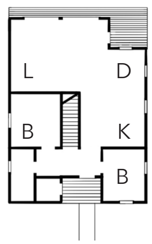
Table 5.10 – SEATTLE-SPECIFIC PROTOTYPES (1950-2000+)

HOUSE BOAT PLAN TYPES

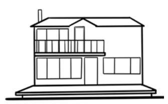
1880 - 2000+

Aka: "House Boat"

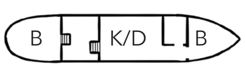
Floating Home



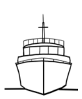
(Plan varies widely)



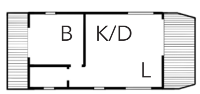
Live-Aboard Boat



(Plan varies widely)



House Barge



(Plan varies widely)

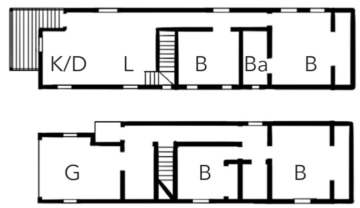
"SKINNY" HOUSE PLAN TYPES

1980 - 2000+

Aka: "Skinny House"

"Skinny" House

Floor 2

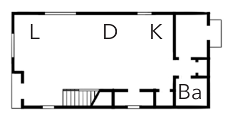


Floor 1

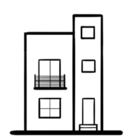
(Plan varies widely)

Due to this plan type's narrow width, it is common to encounter an "inverted" floor plan where garage and bedrooms are located on the lower floor. The kitchen, dining-room, living-room configuration is placed above for programmatic continuity.

Townhouse Type

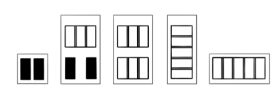


(Plan varies widely)



Jordan C. Legan illustration.

Within the city of Seattle, large lots that previously held a single detached dwelling, are now subdivided to allow additional housing to be built. On narrow lots, houses share similar form and floor plan layout to rowhouse/townhouse groups built throughout the city. This house type will be built independently on a divided lot or take a prominent position at the front of a townhouse group, as shown in plan below.



Firefighters engage in a form of "holistic or global processing of overall patterns" of the house.[81] In "The Holistic Processing Account of Visual Expertise in medical Image Perception: A Review" psychologist Heather Sheridan and others write,

> The holistic mode involves a rapid global assessment of the image, which enables the expert to identify perturbations that could be potential abnormalities. The expert then subsequently initiates a 'search to find' mode, which involves shifting their gaze to potentially relevant locations, as well as scanning the image to locate additional abnormalities that were not salient enough to be noticed during the initial global assessment.[82]

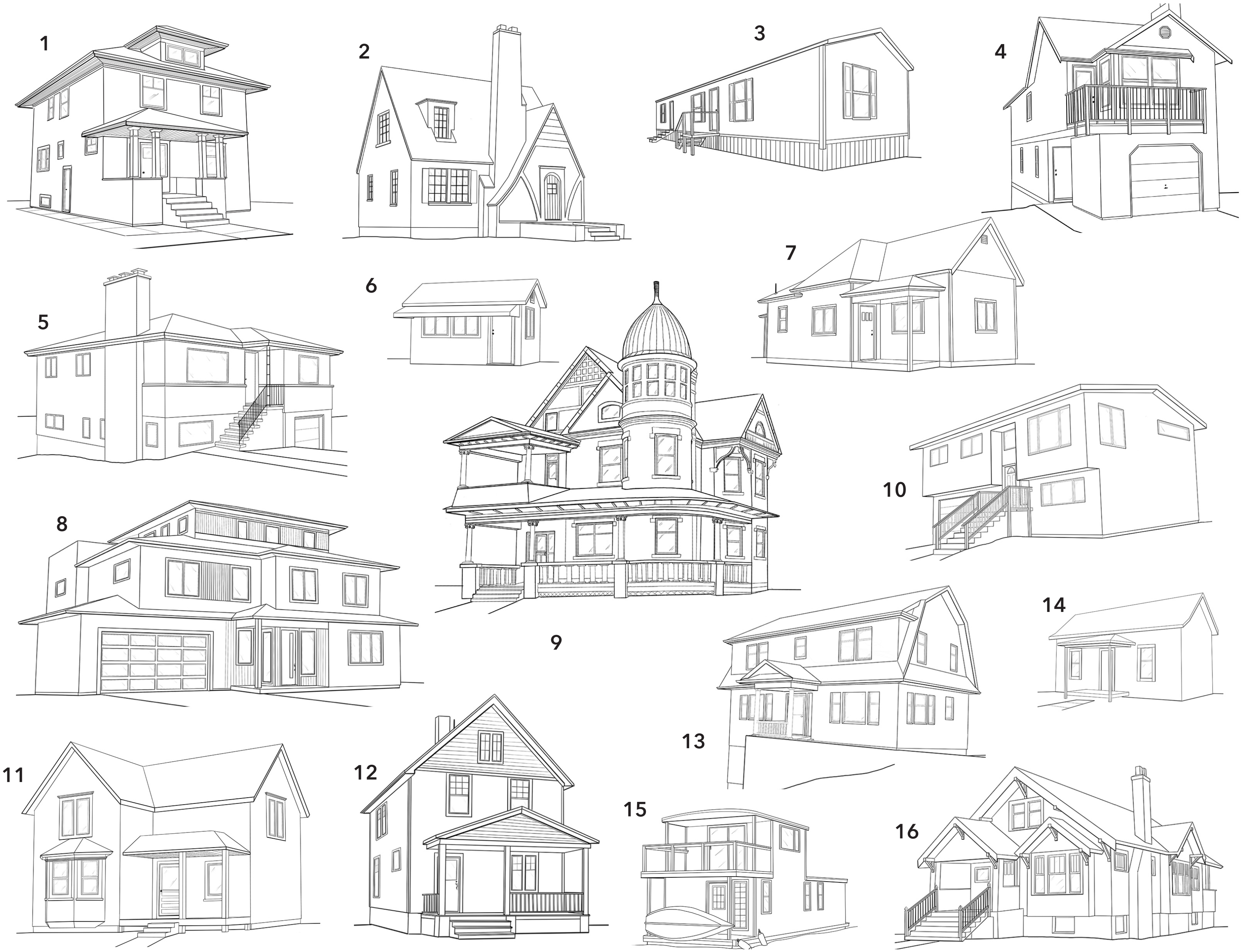
Firefighters rapidly extract a global impression of the house.[83] This impression consists of a comparison between the contents of the retinal image, and one's prior knowledge (drawn from memory, or potentially, from the catalog of types) about the visual appearance of the house.[84] Additionally, throughout the course of their work, firefighters construct "numerous event schemas in mind, representations of the sequences of actions on objects needed to accomplish a task."[85] The "representations of sequences of actions" as Barbara Tversky describes them are shaped by the geometry of houses including the forms (the exterior shape), interior configurations (floor plans), patterns of structural elements (i.e., construction assemblies), and expected fire behavior and smoke movement. The catalog of types simplifies the process for firefighters to assess these aspects under the pressure of time on arrival at a burning house.

On arrival to the scene of a house fire (or any fire), firefighters attempt to separate the *essential* from *distracting* information. Knowing the house types helps to constrain what is possible. Firefighters should be aware that architectural treatment (i.e., style), renovations, furniture, cars, fences, vegetation (i.e., trees, shrubs), fencing, and topography all contribute to confusion. The next page contains an illustrative "test" that firefighters can use to practice recognizing the 16 types. Translating representations from two- to three-dimensions can be challenging at first, just as learning to be sensitive to essential features can be. A fundamental premise behind this "field guide" rests on advice from historians Gabrielle Lanier and Bernard Herman which was reproduced in *Invitation to Vernacular Architecture: A Guide to the Study of Ordinary Buildings and Landscapes*,

> "Buildings are the best teachers of ordinary architecture. Books, drawings, photographs, and written documents are invaluable, but, inevitably, we learn the most about buildings by taking to the field – by looking, evaluating, measuring, questioning, and looking again."[86]

Following the "test" page, the catalog will fully illustrate one example to show how the system helps firefighters "pick-up" essential features of a house on fire.

Figure 5.11 Practice examples. Answers in Endnotes.



Drawings by Jordan C. Legan

5.10 A Practical Wayfinding Example

As a series of interconnected places, there is a useful geometric organization to the configuration of houses that assists wayfinding in smoke. The interior spatial configurations of houses have been shown by architectural historians to follow repeatable patterns, specifically in the ***kitchen***, ***dining-room***, and ***living-room*** configuration. This proves to be an essential organizing principle behind many of the house types (though not all) presented in this catalog. If firefighters are able to rapidly identify this sequence of rooms from the exterior, they will reduce their cognitive demand precipitously once they begin operating inside.

Each of the "units," or rooms that compose a house have a (somewhat) distinct identity. Although functions may change over time, the social identity of spaces stays relatively stable and in construction practice. A room can also be defined by what things one expects to find there, how those things are arranged, and what they "feel like" in smoke. Furniture and flooring are two good examples.

Knowing the house types helps direct the flow of attention and serve as open inventories – containers into which valuable wayfinding information is held and can be acted upon. Upon entering the smoke, however, the firefighter must rapidly translate perceptions into actions. Developing reasonable expectations about what one will encounter inside is essential to maintaining orientation and to successful navigation. Knowing rooms by "feel" connects perceptions distorted by the smoke to volumes of spatial mental models developed in practice beforehand. It keeps the firefighter firmly grounded in reality.

The following example (Figures 5.12 - 5.17) breaks down the bungalow house through the eyes of firefighters. This example presents a number of assessment challenges; thus, it serves as a useful template for systematic examination of each of the house types in the catalog, and for future examinations of other building types. It can be helpful to compare this house to Hubka's two Bungalow prototypes shown earlier. The example narrates a rapid assessment an experienced firefighter might perform. The house is broken down into a series of plan views to explain how the three-dimensional exterior form, or massing, relate to a two-dimensional representation in plan.

Decision points and areas of confusion help the reader understand how and where a firefighter might become disoriented, or even lost, inside a house. The example illustrates how each of the three firefighters' frames of reference (Engine, Ladder, Incident Command) use spatial cues very differently. This section is meant to serve as a template for firefighters to examine other house types.

Figure 5.12 Wayfinding Example

1. The eyes rapidly scan the overall scene for salient cues first. In this example, the roof is the prominent feature that directs image processing and influences the brain's search for further information.

2. The house is deeper-than-wide and appears to be two rooms wide and three rooms deep.

3. The side-gable roof is indicative of a specific type of bungalow, thus, is an essential cue. The dormer and windows indicate occupied space above Floor 1. However, not all Bungalow plans have a second floor.

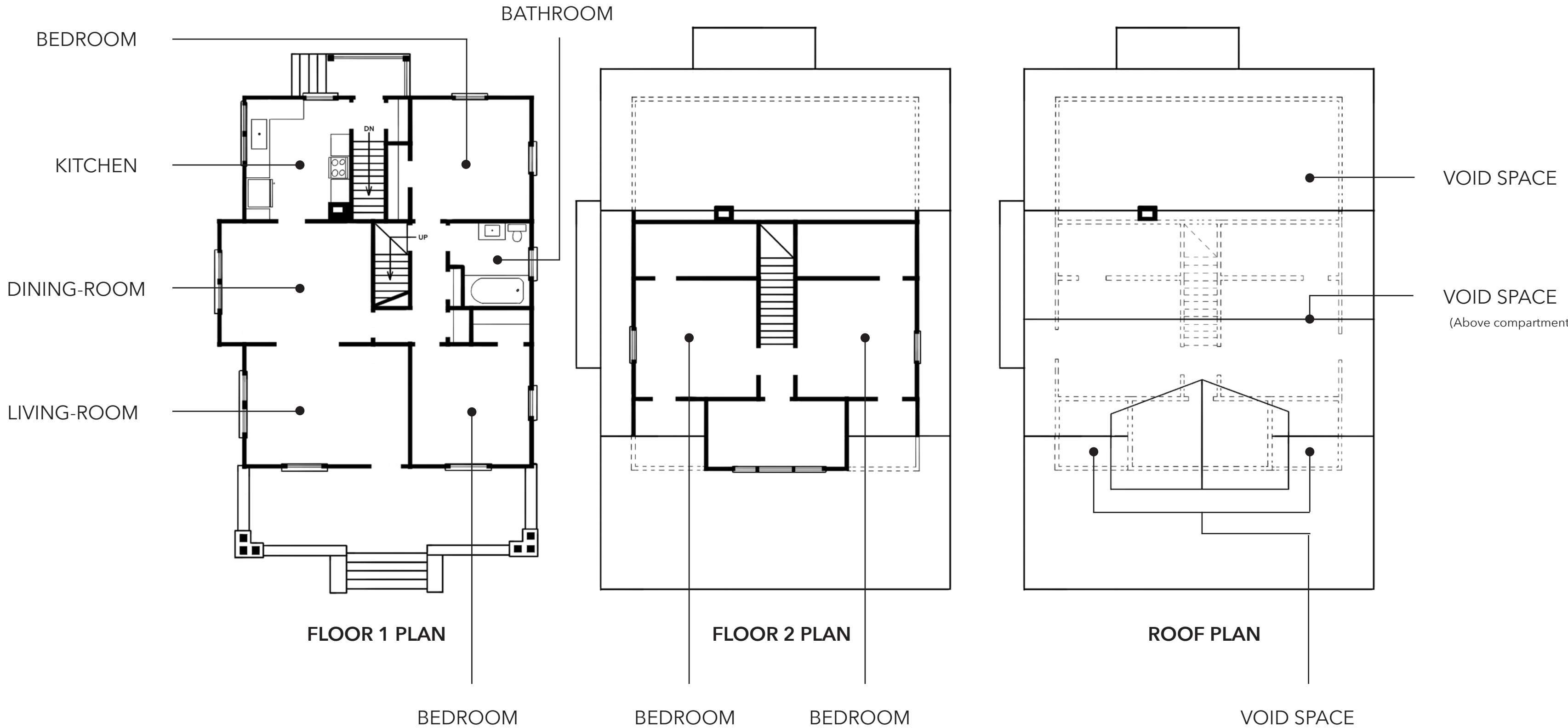
4. The projected bay on Floor 1 is a noticeable (and common) feature of the bungalow plan. In the bungalow plan type, this projection often indicates the dining-room.

5. To the left, the double-wide, chest-height window sill indicates cabinets below. These are often found in kitchens.

6. Since this is a one-and-a-half story house with a cellar (or basement), firefighters will also need to locate the stairs up (and down). However, from the outside it is not clear where they are.

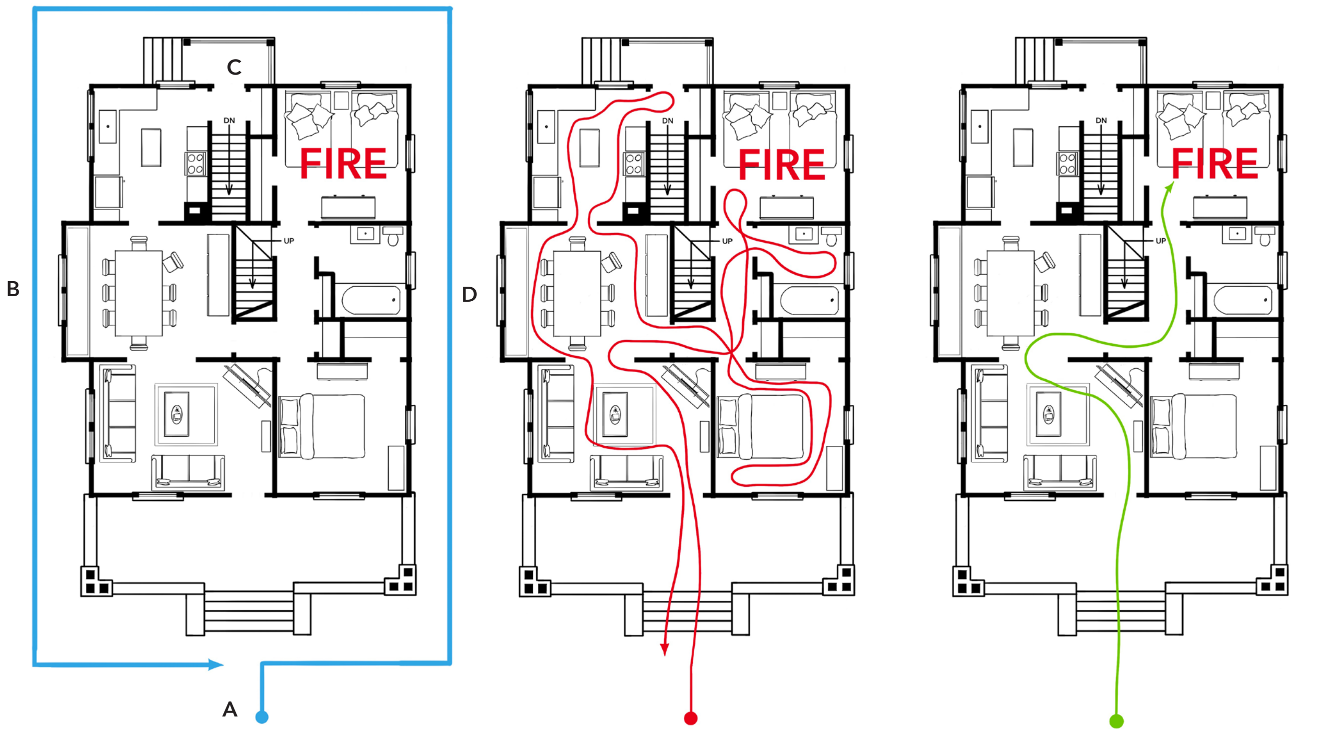
7. With the aforementioned units of information, the brain is able to make an "educated guess" about the configuration of rooms on the left side of the house. From front to back: living-room, dining-room, kitchen. The firefighter will not know for certain if the porch window on the right is a bedroom until the front door is opened. Regardless, it is a safe assumption that the bedrooms on the ground floor are on the right side and upstairs. The roof form dictates a smaller number of rooms upstairs.

Figure 5.13 The Standard Bungalow Plan.



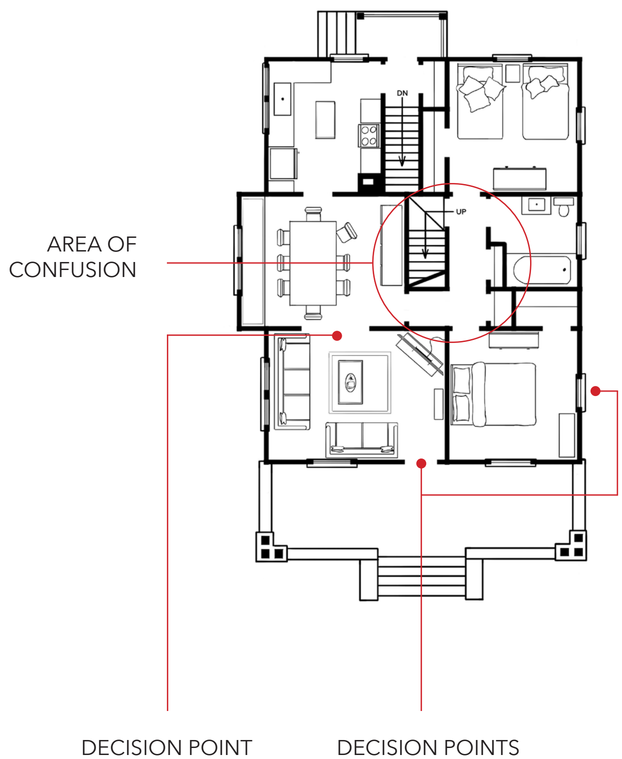
The broad, side-gable roof is common to the large bungalow plan type (see Hubka above), but this house uses the standard bungalow plan. Mixing architectural treatments, forms, and plans is common. As a result, firefighters should hold their assumptions loosely. The assessment of this house is emblematic of the *"if this, then this"* model that firefighters have to use extensively, often having to update it multiple times over the course of their search. What this points to is that firefighters need to have flexible spatial mental models, accessible knowledge, and to practice moving along the egocentric/allocentric reference continuum.

Figure 5.14 Three different frames of reference on the fireground.



The house can be experienced from multiple frames of reference by firefighters on the fireground. The frame of reference shapes what one "sees." For example, *Incident Command* is concerned with tracking the location of firefighters operating on or inside the fire building. They are concerned with the seeing the "big picture." The *Ladder Company* searches ahead of, and often in conjunction with, the engine company to find the location of fire and rescue any victims that may be trapped inside. The *Engine Company* applies water to stop combustion. Most-often, this is done from inside the burning building – from hallways and inside compartments (rooms).

Figure 5.15 Decision Points and Areas of Confusion (Floor 1).

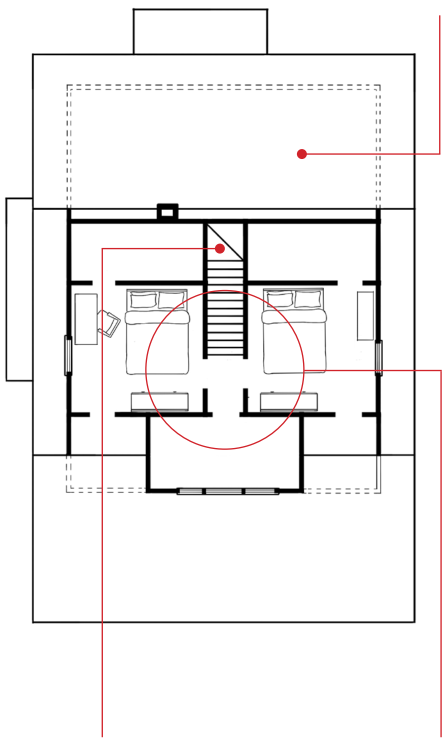


NOTE: In houses built before refrigeration, houses may have an exterior or side staircase. This was to facilitate the delivery of ice and the storage of food in the cellar.

Depending on the task, entry into the house happens through a door (most-often) or a window, for a window-based search, likely due to advanced fire conditions *or* the presence of a known victim. Window-based searches require the firefighter to recalibrate their expectations for the sequence of rooms they will encounter. For example, if firefighters enter the front door, they have been conditioned to expect the living-room, dining-room, and kitchen. When a firefighter enters a window to perform a window-based search, the sequence is different (when and if) the firefighter continues their search beyond the room. This subtlety is rarely discussed in firefighting practice, but is of immense importance to maintaining orientation, for sensemaking, and decision-making.

In the standard bungalow plan, bedrooms are accessed from a hallway that connects to the dining room. It is easy to miss the hallway in zero visibility smoke conditions, especially if one does not expect it. In the standard bungalow plan, stairs are located in two places: *in the bedroom hall* or *in the kitchen*. For example, in this house, there are six doors in the bedroom hall. This adds significant confusion to firefighters operating in that area. Generally, interior doors swing into rooms and out from closets and stairs. In some cases, like in the Bungalow plan, a door may swing to block another.

Figure 5.16. Decision Points and Areas of Concern (Floor 2).

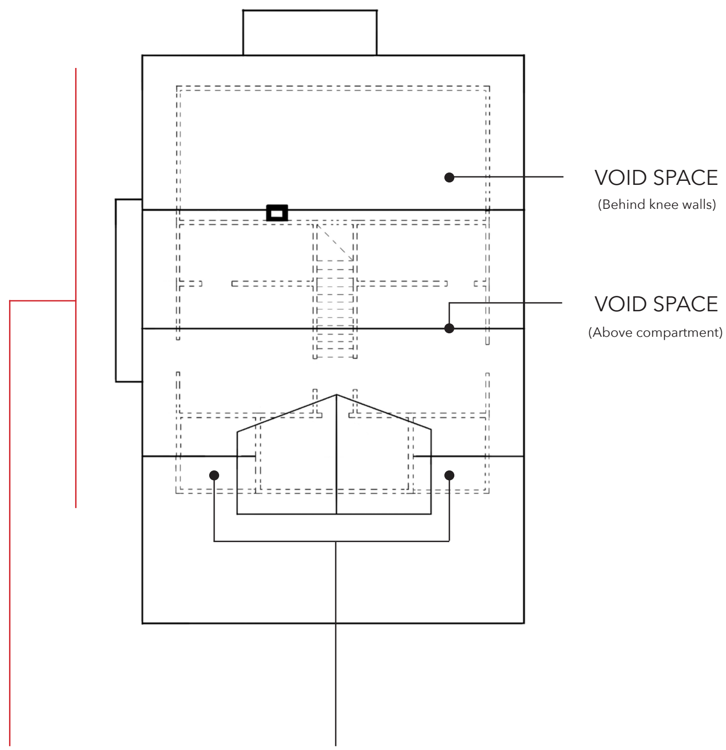


In this example, there is a fire in the Floor 1 bedroom, located adjacent to the stairs. As a result, the upstairs bedrooms are most at-risk. Heat and toxic products of combustion naturally travel upward. If the stairs do not have a door, the Ladder Company faces a critical decision at the bottom of the stairs – stay on Floor 1, or go upstairs. If conditions deteriorate, their only exit would be out the Floor 2 windows. Fire conditions will dictate how they proceed.

For illustrative purposes, firefighters chose to ascend the stairs to search above the fire. If firefighters locate a victim, they will face another choice – to bring the victim out the way they came in or bring them out a ladder placed to the window. Firefighters operating above a fire are in a vulnerable position. The team will seek to isolate themselves from conditions in the stair hall by closing a door.

This team of firefighters must monitor their position on a different floor (with a different floor plan), the route they took to reach the victim, fire and smoke conditions, and their air supply. A common problem firefighters face when ascending or descending from the point of entry is making accurate "educated guesses" about the floor plan. In general, people tend to believe the layout repeats itself, but in many house types, this does not occur. Firefighters need to be aware of and practice adjusting their spatial mental model when they transition to another floor.

Figure 5.17 Decision Points and Areas of Concern (Roof).



The drawing on the left illustrates the floor plan underneath the roof. Firefighters operating *topside*, are concerned with identifying two principle areas – *compartments* and *void spaces*. They need to know where the fire is burning and they need to understand their position on the roof in relation to the fire. In this example, firefighters would need to determine whether or not fire communicated into the void spaces above the fire compartment.

At top floor fires only, Ladder Company firefighters perform vertical ventilation. The purpose of vertical ventilation is to create a "chimney effect" that allows pressurized, toxic gasses and heat energy toxic a way to exit the structure. Vertical ventilation, in close co-ordination with the Engine Company performing fire suppression, vertical ventilation can dramatically improve conditions inside the compartment and adjacent spaces.

Firefighters assigned to perform vertical ventilation will throw ladders (or use an aerial ladder) to access the roof and cut holes over the top of, or as close to over the fire, as possible. This task requires that the Ladder Company make "educated guesses" about the floor plan beneath them. In many cases, smoke obscures vision on the roof, making this task difficult. Increasing the level of difficulty are the wide-range of roof shapes, pitches, and add-ons such as dormer windows, and solar panels.

5.11 Wayfinding Inside Houses

An expert in the field of spatial analysis, architect John Peponis, writes in "Finding the Building in Wayfinding," that there is a "link between the general intelligibility of built form and specific wayfinding performance."[46] He refers to this concept as *"search structure."*[47] He continues by writing, "buildings, as purely spatial configurations, make themselves available to search in different ways."[48] Researcher Alan Penn adds in "Space Syntax and Spatial Cognition," that the concept of "search structure" is "useful, particularly since it distinguishes two aspects of cognition, which are often conflated in the literature. These are the path – which must be used to find a specific destination, and is therefore presumably of importance in wayfinding performance – and the understanding of what the overall configuration of a building is like."[49] For example, firefighters tasked with searching for people trapped inside a burning house are at the greatest risk of becoming disoriented.

When firefighters begin their search from a familiar location, like the front door the brain can rely on familiar spatial mental models. The front door is generally the primary entry point into a dwelling. The expected sequence of rooms influences expectations. When a firefighter enters the structure through a different entrance (two good examples are windows and rear/side doors). A firefighter might begin their search from a different location because of advanced and extensive fire conditions that prevent firefighters from using the main entrance. Entering a house from these openings violates well-established experience and associated expectations. It forces the mind to perform mental rotations that reorient expectations and require the use of a different spatial mental model.

These examples illustrate how spatial configurations of the house types force firefighters to assess them differently. When entering from a location other than the front door, firefighters must adopt a spatial mental model from a perspective that is far-less practiced and understood. Making sense of this rotation requires additional attentional resources. It places additional demand on the working memory (WM) in situations where the firefighter is typically operating near capacity. The same thing happens when firefighters transition levels inside the house. The same layout rarely transfers to another floor.

Additionally, firefighters rarely wayfind inside empty houses. Unlike during training, firefighters do not maintain orientation primarily on a wall. Houses are filled with one's possessions. Firefighters find their way using walls and landmarks such as furniture constantly. As one moves through and between rooms within the house, firefighters should be alert to other subtle cues such as changes in flooring, furniture and the proximity (and swing) of doors to one another. Successful navigation and continuous orientation are dynamic skills that must be practiced within context.

The catalog is a simple cognitive scaffolding for visual inquiry and wayfinding in smoke. It helps firefighters orient to the spatial organization of a building – a critical component of wayfinding in smoke. This thesis addresses a real and systemic problem within the American fire service – that there exists no systematic method to recognize, name, interpret, and discuss characteristics of house types. The initial size-up of the building is an essential precursor to wayfinding in smoke and fire suppression. An essential firefighting skill is the ability to strip away distracting information to focus one's limited attentional resources on features of the building that will help them orient and navigate.

5.12 Conclusion

Memory aids of all types have proven useful to wayfinders throughout human history, for good reason – the brain can only hold a limited amount of information in short-term (working) memory. Because of its inherent limitations, human brains organize information into chunks and schema (or templates). For firefighters, houses can perform a mnemonic function because of their relative permanence and one's familiarity with them.

The spatial features of this environment are "written into" the circuitry of a firefighter's brain through personal experience, training, and emergency work. In *Spatial Recall: Memory in Architecture Landscape*, Marc Treib writes, "we internalize our experiences as lived situational, multi-sensory images, and they are fused with our body experience. Human memory is embodied, skeletal and muscular in its essence, not merely cerebral."[50] Through repeated exposure, firefighters come to (unconsciously) know certain spatial characteristics of the proposed house types, but often in a general and unsystematic manner. The catalog of house types introduces firefighters to a standardized approach for identifying houses and predicting their interior configurations. In an effort to improve how firefighters orient to the organizational (or spatial) characteristics of the different house types. The typology reduces the enormous numbers of different houses to a more manageable number of types to learn. The next chapter examines how the catalog can be used effectively *before*, *during*, and *after* the fire to transmit knowledge and improve the quality of firefighters' understanding the residential built environment.

ENDNOTES (Chapter 5)

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Answers:

1). Four-Square Plan, 2). Period-Revival Plan, 3). Mobile Home Plan, 4). "Skinny" House Plan, 5). Ranch Plan, 6). One-Room Plan, 7). Parlor-By-Pass Plan, 8). Suburban Developer Plan, 9). Victorian Plan, 10). Split-Entry Plan, 11). Side-Gable Plan, 12). Side-Hall Plan, 13). Two-Room-Deep Plan, 14). Two-Room and One-Room Deep Plan, 15). House Boat Plan, 16). Bungalow Plan.

CHAPTER SIX

The Catalog as a Tool of Thought, Memory, and Action

"It is because craft skill or tacit knowledge is such a fundamental component of knowledge production that accounts of its generation, transmission, acceptance and application cannot be given solely in terms of texts and inscriptions. A vital component of local knowledge is moved by people in their heads and hands."[1]

– David Turnbull

6.1 Introduction

The catalog of house types presented in Chapter 5 is meant to be a practical tool to help firefighters wayfind in smoke. First, the catalog is designed to help firefighters recognize, document, and communicate about spatial patterns in common types of houses *before a fire*. Second, while the physical catalog has limited use *during a fire*, knowing the types of houses in the catalog helps the brain locate spatial information faster – the catalog can be thought of as a set of "cue cards" telling the brain where to look for the information it needs. Third, the catalog can be used as a tool to help firefighters transfer knowledge and experience *after a fire*. Firefighters have a rich oral tradition. It is the primary tool firefighters use to share knowledge and experience. Storytelling, in particular, "occurs in every culture and from every age. It exists (and existed) to entertain, to inform, and to promulgate cultural traditions and values."[2] Current educational models do not explicitly teach firefighters about the value of heightened attention to subtle details, nor do they systematically teach firefighters "what to look for." Within the safe confines of the kitchen, firefighters weave essential details about their experience into the stories they tell. Their experience navigating inside burning buildings and descriptions of sensory details are incorporated into existing firefighting mythology, culture, and practices.

There is a need to make the built environment, specifically houses (and the language of architecture, to a lesser degree) more intelligible and accessible to firefighters. The catalog is meant to be the "picture" to go with the words. According to writer John Ruskin, *drawing*, as a sensemaking tool, is a means to "set down clearly and carefully, records of such things as cannot be described in words, either to assist your own memory of them, or to convey distinct ideas to other people."[3] Marc Treib writes that the hand drawing, "comes with no default positions: we express what we want; it may be quick or it may take hours to complete; the sketch pad and pencil are portable and go where we go; drawing as a procedure is immediate."[4] Simple writing tools and a surface upon which to write have been used effectively in various forms throughout human history to serve as a record one's observations and experience.

It is no secret that one "sees" a whole range of things yet observes — or is aware of — far less. In *Visual Intelligence* art historian Amy E. Herman writes, "although we frequently use the terms interchangeably, seeing can be thought of as the automatic, involuntary recording of images. Observing is seeing, but consciously, carefully, and thoughtfully."[5] Current educational practices in the fire service have all but ignored the need to train firefighters to observe and pay attention to "what matters" – to make note of typical and exceptional occurrences, to recognize patterns, to ask questions, to look for clues or signs, and document experience related to fighting fires in houses. This chapter encourages firefighters to observe houses more closely and offers methods to help improve acute observation skills by using visual inquiry strategies such as: *thinking routines*, *field notes*, and *storytelling*. It explains why these are essential tools for improving firefighters' wayfinding practices in burning buildings.

PART 1 — ENABLING THE TRANSFER OF KNOWLEDGE

6.2 Making the Residential Built Environment "Legible"

The catalog of house types aims to bring an interpretive order to the residential built environment, specifically houses, where fires occur most often. A primary aim of the catalog is to make houses "legible" and enhance familiarity and learning prior to a fire — a time when firefighters are not dealing with the pressure and acute stress on the fireground, where firefighters must be sensitive to subtle environmental cues. Firefighters' decisions on the fireground have been shown to be largely unconscious, or "automatic" and based on a rich storehouse of previous experience.[6] Firefighters filter through seemingly messy, chaotic, and random sensory and experiential information to rapidly retrieve a mental model from memory by making associations to memories of past experience. Firefighters do not learn to do this during a fire, they learn beforehand.

6.3. Thinking Routines

Looking and questioning take no special training or skill. There is no one way to see, but firefighters need to be able to interpret the house types in a consistent manner, because critical decisions and communications are based on rapid assessments performed by multiple people from different perspectives, backgrounds, levels of training, and firefighting experience. Thus, "we cannot assume that anyone else sees what we see, that we see what they see, or that either of us accurately sees what's really there."[7] The catalog of house types structures firefighters' inquiry into house types by focusing their limited attentional resources on patterns that support identification of the floor plan before entering the building. In order to wayfind, one must "identify salient features of his or her surrounding environment and match those features with the same features in long-term spatial memory. This point becomes particularly evident when attempting to reorient after becoming lost."[8] The catalog of house types is a tool to make firefighters' tacit knowledge explicit and accessible under stress, and more usable, in general.

Wayfinding in smoke is a complex task. The experience is made complex in a myriad of ways, but the brain has evolved to adapt quickly to dangerous environments. In certain situations, like those that firefighters find themselves in quite often, a single piece of information, often one cue is necessary to decide on a course of action. Houses, when categorized by plan types, provides a number of cues that help the firefighter make "educated guesses" as to the spatial organization they may encounter (but may not be able to see). These educated guesses employ mental shortcuts called heuristics. Heuristics are rule-of-thumb strategies that "shorten decision-making time and allow people to function without constantly stopping to think about their next course of action."[9] Heuristics allow one to problem-solve and make judgments rapidly and effectively by linking a *cue* with an *expectation*. For example, firefighters are taught to "BAG the fire." Translated, the phrase directs firefighters to think about the following questions: Where has the fire *been*? Where is it *at* now, Where is it *going*? Another useful example teaches firefighters to look *low*, *middle*, then *high* at the house itself. This routine helps firefighters identify the fire's location before committing to a position above a lower floor, or basement/cellar fire. This thesis proposes that firefighters use a similar routine to identify the spatial organization of houses. Identifying the *kitchen*, *dining-room*, *living-room* sequence is an essential first step in orienting to the type of house on fire.

In *Mind in Motion: How Action Shapes Thought* Tversky writes "when making decisions about navigation or judgments of distance or direction or sketching maps, people can make explicit inferences as well as implicit ones. This makes spatial judgment and navigation the same as problem-solving any problem: gather whatever information seems relevant and try to make sense of it."[10] Wayfinding in smoke requires sound decision-making in an environment where it is difficult to know what is important and what is not. There is no time to gather all the information necessary to make a "perfect" decision. What firefighters do is create a set of useful heuristics that guide their actions, but they rarely talk about the heuristics they store in mind. These routines are burned into the circuitry to the point that they are unconscious, largely inaccessible. The catalog of house types is meant to help firefighters articulate what they know, but cannot "say," improve existing heuristics, and give firefighters a simple framework to establish new ones.

6.4 Knowledge Transfer in Firefighting Practice

Very little about firefighting practice (especially wayfinding) is written down, to the detriment of educating subsequent generations of firefighters. Experience and domain-specific knowledge within firefighting practice is shared almost exclusively in oral form. Firefighting is taught or modeled to other firefighters primarily through storytelling. Storytelling has a role in firefighting education and training, in which stories and scenarios are often used to illustrate and guide novice firefighters. Firefighters make sense of their experience by talking about it.

In *Masons, Tricksters, and Cartographers: Comparative studies in the Sociology of Scientific and Indigenous Knowledge*, scholar David Turnbull writes that the problem of "science and technology, is not the putting theory into practice, but of the transmission of practices."[11] David Herman continues,

> Knowledge can be transmitted in a variety of ways. It can be by word of mouth. It can, as [Gaston] Bachelard suggests, be 'frozen' into the technique…It can also be transmitted through education and the establishment of a tradition. A tradition may or may not include theories and texts but always includes training, development of skills, and the knowledge and observation of other structures and solutions.[12]

Storytelling as a means to transfer knowledge is ubiquitous to firefighting practice and is an especially powerful tool for communication and knowledge transfer. A *story* "conveys a range of meanings, from anecdote, to exemplar, to something that is invented rather than 'true.'"[13] Storytelling expert Kendall Haven in *Story Proof: The Science Behind the Startling Power of Story* defines a *story* as: "A detailed, character-based narration of a character's struggles to overcome obstacles and reach an important goal."[14] It is easier "for the mind to extract and understand" the context and relevance when experience is structured in story form.[15] Most stories are structured to include an *inciting incident*, a *progressive complication*, a *crisis*, a *climax*, and a *resolution*. Within firefighters' storytelling practices, however, little thought is given to the *setting*. Fires take place somewhere — and the majority of them take place in *houses*, where civilians are most at-risk.

Firefighters tell a specific type of story. They tell *"vignettes"* — a simulation of real events in short story form — told in vivid detail. The vignette is a snapshot of one's firefighting experience; a small, verbal illustration describing a moment (or series of moments) in time. Vignettes direct one's attention to a specific element or elements of complex processes. Within the vignette, firefighters elaborate on experience gained from fighting fires including valuable information about fire conditions and their actions. These vignettes contain "all the types of information an expert would attend to in that situation to solve the problem posed, and the problems presented are those with which experts have grappled."[16]

In "Out of the Closet: The Importance of Stories and Storytelling in Planning Practice" historian and urban planner, Leonie Sandercock writes that stories (like the vignettes firefighters tell) have certain properties:

> First, there is a temporal or sequential framework…Second, there is an element of explanation or coherence, rather than a catalogue of one thing after another. Third, there is some potential for generizability, for seeing the universal in the particular…Fourth, there is the presence of recognized, generic conventions that relate to an expected framework, a plot structure and protagonists.[17]

Sandercock's statement begins to describe the storytelling framework used by firefighters, but there is more to firefighting vignettes. Firefighters' stories include characters (engine and ladder firefighters, and chief officers), a taxonomy of techniques (successful and failed), place names (sometimes…), policies and tactics, personal experience, tales of fear and overcoming, details, and some spatial information. In this context, firefighter stories become a sort of heuristic that allows the teller to "safely leave things unstated that it would otherwise take far too much time and effort to spell out, and interpreters can make sense of those abbreviated reports, which would otherwise remain hopelessly elliptical and opaque."[18] The vignettes provide the listener (especially novice firefighters) perceptual cues, factual information, and cause-and-effect relationships, and decisions in the context of specific house types with specific fire and smoke conditions. These vignettes allow firefighters access to a body of knowledge and experience that they may not have (or ever get) otherwise. In "From the Recognition Primed Decision Model to Training," Ross et al., write that much of an expert's knowledge is "tacitly held and involves recognitional routines so well learned and familiar that the expert may be unaware of drawing on that knowledge or going through the process of making an intuitive decision."[19]

It is not hard to understand why storytelling practices evolved to help humans make sense of their experience. Ross et al., write "stories represent our most powerful means to transfer expertise and allow the learner to activate that expertise in new situations. The story is a package for describing the important causes and effects to which we want to draw attention. It is through constructing and understanding stories that we make sense of the world."[20]

Stories, then, provide a "cognitive template, a paradigm for segmentation, that guides both the production and the interpretation" of units of information.[21] They allow "***pre-processing***" and "***post-processing***" giving the brain the ability to run various simulations of actions and consequences before, during, and after the fire. As cognitive narratology researcher David Herman describes, pre- and post-processing the world "saves processing the representation of the world. Put another way, the greater our understanding of the organization we maintain outside, the less we have to memorize."[22] The brain's ability to preprocess, or practice, is essential in time-compressed environments like that of a fire. Pre- and post-processing allows the brain to compare the typical against the actual – to establish a baseline expectation and identify anomalies necessary for rapid decision-making. The stories firefighters tell include elaborate descriptions about actions taken (or not taken) and details about the environment, including fire/smoke behavior, spatial organization, and cues. Though not explicitly stated, firefighters are expected to make perfect decisions. This is impossible, however, because the environment is "too complex, time is too short, and not enough clear indicators are available."[23] But storytelling allows firefighters to simulate before and after, the effects of different decisions as a way to practice making decisions. Stories are a means of low-risk experimentation, or practice. Philosopher Matthew Crawford, in his book *Shop Class as Soulcraft: An Inquiry into the Value of Work,* writes that problems do not often present themselves in a predigested way, rather

> There is too much information, and it is difficult to know what is pertinent and what isn't. Knowing what kind of problem you have on hand means knowing what features of the situation can be ignored. Even the boundaries of what counts as 'the situation' can be ambiguous; making discriminations of pertinence cannot be achieved by the application of rules, and requires the kind of judgment that comes with experience.[24]

Image 6.1 Fire Department of New York (FDNY) Firefighters telling stories between alarms in the kitchen. Andrew Hinderaker photo.[83]

Stories, then, are a powerful sensemaking tool. As operational theorist, Karl Weick points out that "sensemaking involves turning circumstances into a situation that is comprehended explicitly in words and that serves as a springboard into action."[25] He concludes by saying that "sensemaking is, importantly, an issue of language, talk, and communication."[26] Nowhere is this more apparent than when firefighters talk about their experiences with one another.

6.5 Chunking Experience

Storytelling breaks firefighting experience into identifiable "chunks." In firefighting practice, experience is often segmented into "bounded sequences of ***states***, ***events***, and (human) ***actions***," as David Herman has described.[27] Changes in ***state*** (a period of time where one's behavior is stable; for example, normal firefighting operations), ***events*** (a moment in time that may disrupt behavior; for example, a firefighter falling through a hole in the floor), and ***human actions*** (for example, a poor tactical decision that causes the fire to grow or puts firefighters in grave risk) segments the firefighting experience into temporal units which "frame" different episodic memories.[28] These frames, similar to a comic strip, control or direct the listener's attention when relayed as part of a story. Haven writes that a "story is a 'thing,' a specific narrative structure. It is the framework – a narrative architecture. According to Herman, stories address the,

> Problem of how to chunk the ongoing stream of experience into bounded, cognizable, and thus usable structures. Stories organize experience by enabling people to select from among the total set of sequentially and concurrently available inputs; preprocess those inputs into internally differentiated chunks with a beginning, middle, and end and then use those temporally structured segments as a basis for further cognitive operations on new experiential inputs.[29]

Story is not the content, but the scaffolding upon which some content (fiction or nonfiction) is hung."[30] The narrative structure can be used in both a targeted and opportunistic fashion.[31]

This has implications for how firefighters make sense of the environment while they wayfind in smoke. Stories chunk firefighting experience into "structures for representing and remembering stereotypical situations" because it is easier to organize knowledge and behavior if experience is subdivided into manageable segments.[32] Stories provide the structure for "connecting otherwise isolated data into elements of episodes or 'scenes.'"[33] Stories allow one to "impute casual links," or to recognize relationships between episodic memories that would normally be thought of as random, chaotic, and isolated.[34]

6.6 Sequencing Behavior

Storytelling supports the sequencing of firefighting behavior by modeling, ***who***, ***what***, ***when*** and ***where*** "a particular course of action can or should be pursued."[35] Stories tell lessons about "what exactly should one do, where, when and in what order."[36] Additionally, stories "function to support human navigational abilities, representing how agents might pursue a particular trajectory through a complex, dynamically emergent spatial environment."[37] Thus, stories allow firefighters to practice various wayfinding tasks such as orientation and navigation without consequence. According to Herman, stories "of all sorts can function to support human navigational abilities, representing how agents might pursue a particular trajectory through a complex, dynamically emergent spatial environment."[38] Clearly, stories are a template for decision-making related to wayfinding in smoke.[39]

6.7 Distributing Knowledge

In an oral culture such as firefighting, essential knowledge and culture are preserved and transmitted orally and through tradition and ritual. It is evident that a large amount of information is accurately preserved and passed on to generations of firefighters. Firefighting knowledge is encoded into memory through stories and rituals that take advantage of "group learning and testing sessions, using mnemonics, having overlapping and redundant ways of connecting the knowledge and constructing material models of the systems, like stick charts and stone arrangements."[40] During the process of telling, interpreting, and retelling stories, domain-specific knowledge and traditions are solidified into something transportable. Firefighters spend time listening to other firefighters' stories, and willingly spend the days practicing skills and talking about fires. Through stories told after-the-fact, experienced firefighters teach or model behavior to novice firefighters.

Ultimately, what the novice firefighter needs is a structure to understand what the experienced firefighter is trying to convey. Within five minutes, in the kitchen listening to the stories firefighters tell about past fires, it is apparent that firefighters intuitively understand and use story structure. What is missing, however, is a structure that orients the listener to spatial aspects of the experience being recalled. This is where the catalog of house types can play a significant role. The catalog can help unlock the tacit knowledge that expert firefighters clearly have but have trouble articulating by orienting the storyteller and the listener to something stable (for example, the floor plan). The catalog makes explicit the common spatial organizations of house interiors, puts place-names to the types of houses, and provides a simple framework for discussion. As a result, the catalog of types can be thought of a tool that associates "doing and thinking, navigating and knowing," and talking about firefighting experience.[41]

6.8 Visual Inquiry Routines

Harvard Graduate School of Education's "Project Zero" offers a useful investigative model for art history students, but it can also be useful for firefighters. Its "Parts, Purposes, and Complexities" thinking routine is used to help visual inquiry students make careful, detailed observations about works of art. Students using this strategy "come to appreciate the complexity of parts, and interactions by seeing how objects and systems have multiple parts — some of which are hidden or not immediately obvious — and how those parts fit or work together to serve one or more purposes and to create a larger whole."[42] One begins by asking the following questions about the thing being examined: "What are its *parts*? What are its various pieces and components? What are its *purposes*? What are the purposes of each of these parts? What are its *complexities*? How is it complicated in its parts and purposes, the relationship between the two, or in other ways?"[43] Cambridge scientist William Ian Beardmore Beveridge writes that the

> Training in observation follows the same principles as training in any activity. At first one must do things consciously and laboriously, but with practice the activities gradually become automatic and unconscious, and a habit is established.[44]

Herman offers this advice to those just starting out: *Look first* then *consult other preexisting information or opinions* then *look again.*[45] Visual inquiry is a type of detective work that teaches one to be sensitive to things others overlook and to accumulate clues and knowledge about local conditions.[46] John R. Stilgoe writes in *What is Landscape?* that "inquiring into what is noticed visually means getting the details into words, and often getting tired or lost in the process."[47] He advises serious inquirers to look often, sometimes sideways, and put words to things. Serendipitous exploration and visual scrutiny of the type advocated by Stilgoe, Tishman, Beveridge, and Herman (among many others), is a learning tool unacknowledged by fire service educators nationwide.

*6.9 **Field Notes and "Messy Diagrams"***

As they are studying houses, firefighters will learn and remember far more if they make *field notes*. Records made in the field have proven to be very effective for learning and knowledge transfer in other occupations. Learning to observe, record, and compare things are components of the scientific method. An essential tool for record keeping in scientific disciplines has been the field notebook or journal — a place to document experience, observations, ideas, inferences, representations, and questions. It is a place to carefully but rapidly record and test observations of phenomena. In her book

Slow Looking: The Art and Practice of Learning Through Observation Harvard lecturer Shari Tishman writes that field notes," help train the eye of novice observers – and refresh and recalibrate the eye of experts — by highlighting what to look *for*."[48]

The different kinds of representations found in field notes are selective; "they schematize, including some information, omitting other information, and often simplifying and exaggerating the information included."[49] Representations produced by hand "take advantage of human capacity to reason about space, to estimate distances and direction, to mentally transform spatial arrays, and to infer function from structure."[50] They are portable and can be produced rapidly.

Firefighters' domain-specific knowledge and expertise is not well documented. There are few "field notes" for novice firefighters to study, examine, or learn from. In order to learn, novice firefighters watch, listen, and perform under the supervision of more experienced firefighters. Firefighting practice is basically *performative* (not representational), meaning that firefighters have developed sets of "open-ended practices or strategies for handling uncertainty," and telling others about their work.[51] (In contrast, architects, and other trade occupations rely primarily on graphic representations, rules, codes, or plans). There is, however, common ground between performative firefighting practices and representational practices used by architects, engineers, and tradespeople — the diagram. Firefighters and architects both use diagrams, albeit differently, to help them make sense of a building, but, in contrast to architects, firefighters are not taught a systematic method for understanding and communicating features of houses. Architects communicate primarily through elevation, plan, section, and perspective. They are taught a specific language and methods to represent houses and communicate its features to others. The fire service has no equivalent pedagogy or standardized language to describe (with words and graphics) the experience of firefighting. Storytelling practices of firefighters can be improved by giving firefighters the ability to consistently describe, or "paint a picture" of the type of house where they gained their valuable experience. The proposed catalog provides that.

Representations can take many forms, but this thesis is concerned with teaching firefighters to document their experience using a specific type of graphic representation — the *"messy diagram,"* a term Tversky uses to describe impromptu graphic representations.[52] She explains that these are "crucial for thinking through problems, arousing and considering multiple possibilities."[53] Their messiness is beneficial because "because ambiguity allows reconfiguration and reinterpretation, ambiguous sketches promote discoveries and inferences. Expert designers excel both at reconfiguring ambiguous sketches and at remote associations."[54] According to Tversky, these kinds of messy diagrams,

> Could be called *bottom-up diagrams*. They are distillations and rearrangements of depictions of aspects of the world, scenes, and events. They seem to begin with the complex world, select and refine depictions of parts of it, and then rearrange those to articulate conceptual correspondences, using visual devices like points, blobs, lines, and frames and spatial Gestalt devices like grouping, orders, rows, and columns.[55]

In "Tools of Thought" Tversky writes that they often include circles, dots, lines, boxes, arrows, and text that "form a small set of graphic but non-depictive elements or glyphs that serve as skeletal elements, a partial semantics, for constructing a wide range of diagrams for a broad range of domains."[56] The benefit of the "messy diagram" is that it takes no skill or specialized training to produce and use, so firefighters can take advantage of them in many situations – before during, and after the fire. Like a map, the messy diagrams firefighters should be taught to produce schematize and present information important for the task at hand – wayfinding in smoke.

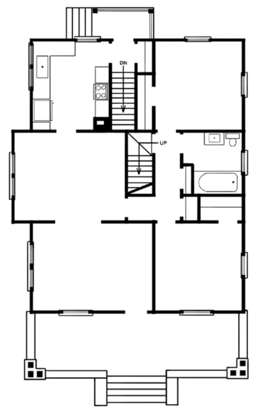
Currently, the closest most fire departments come to documenting firefighting experience is though the *company journal*. The company journal is the record kept by the firefighter on the "watch." The

Image 6.2 Washington D.C. Fire Department (DCFD) Engine 23 "company journals." Jordan C. Legan photo.

watch desk was and still is the hub for information coming into the firehouse. Here, a firefighter monitors and meticulously documents the shift's roll call, phone calls, department messages, alarms, and activity across the city. The company journal records "the mundane and the significant" events of the shift.[57] In some company journals, brief accounts of firefighting activity on alarms are included, but the company journal is used primarily as a time-stamped ledger of the day's unit, station, and shift activities. The company journal, while a valuable record, includes very little in terms of qualitative detail about firefighting practice. First-hand accounts of firefighting experience are maintained primarily in memory. Unfortunately, the meticulous record keeping found in a fire station's company journal is not carried into other aspects of firefighting practice, specifically documenting firefighters' experience wayfinding in smoke. Few field notes exist documenting this experience.

The simple representations used most-often in field notebooks allow for certain information to be rapidly recorded. For firefighters, messy diagrams are a rapid sketch of the house floor plan including event characteristics such as location of fire, obstacles, the location of units operating, and the like. One version of the messy diagram could be a schematic representation of the spatial organization of the house – something meant to be "worked with, "presumably to be used for understanding and inference;" and used as a sort of mental model. [58] Messy diagrams of this sort contain "not only depictive elements but also words and symbols as well as graphic elements that are non-depictive, such as frames."[59] It should be noted that a messy diagram needs no formal training or skill. The point is *not* to create a precise architectural drawing, rather its purpose is to create a record of thought, action, and firefighting "know-how."

For the firefighter, the primary purpose of the "messy diagram" would be to make the house intelligible by simplifying its floor plan into a configuration of simple shapes, paths, and places. It would emphasize the information likely to be helpful for constructing wayfinding inferences and omits the information that is irrelevant and distracting.[60] The messy diagram could serve as a tool to structure one's thinking about wayfinding problems – orientation and navigation. The graphic convention behind the messy diagram is meant to be rapid, something useful in the field, at the kitchen table, and in training. The messy diagram is a powerful "no skills required" example of an ideographic language. Precision and accuracy are not important, at least not initially. Most importantly, a diagram can be realized quickly. It gives the firefighter a simple adjunct onto which one can off-load perceptions, observations, thoughts, and experiences. If it is to be used by firefighters, it has to be simple.



Step 1: Determine the house's *width* and *length* (in terms of rooms wide versus deep), then represent the compartments as circles. Do not worry about metric accuracy, rather, focus on the configuration.

Step 2: Add the walls and other relevant *interior* and *exterior* features of the house and the site. The key here is to separate distracting architectural details from the informative ones.

Step 3: Add *labels* and *notes* that serve as memory aids. The framework of this diagram should take no longer than 30 seconds. These diagrams are meant to be a rapid field reconnaissance adjunct.

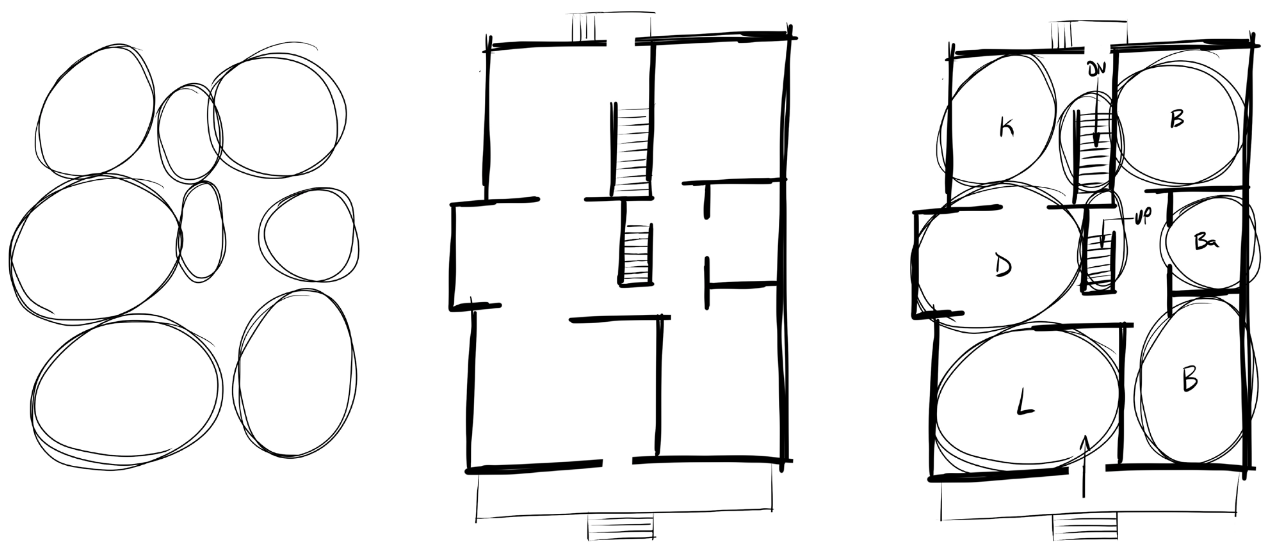
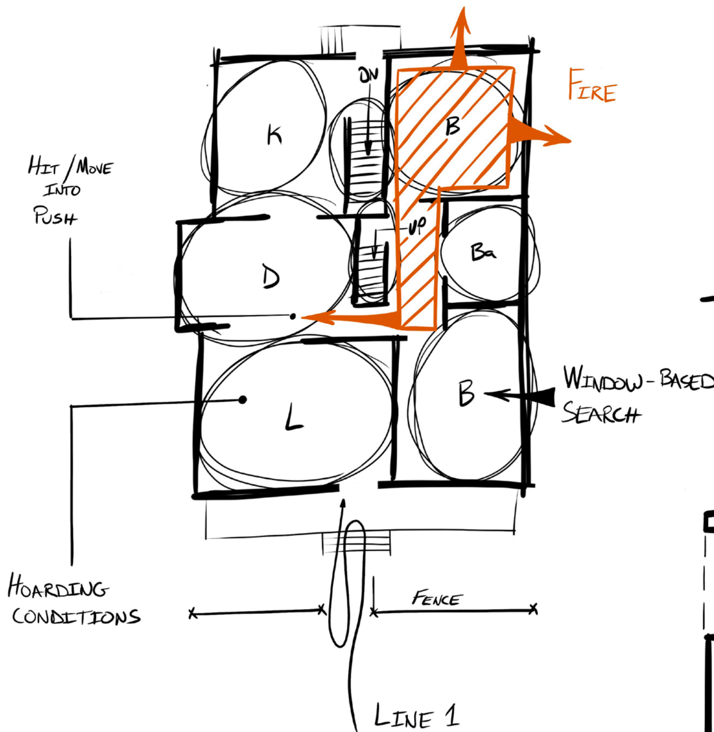
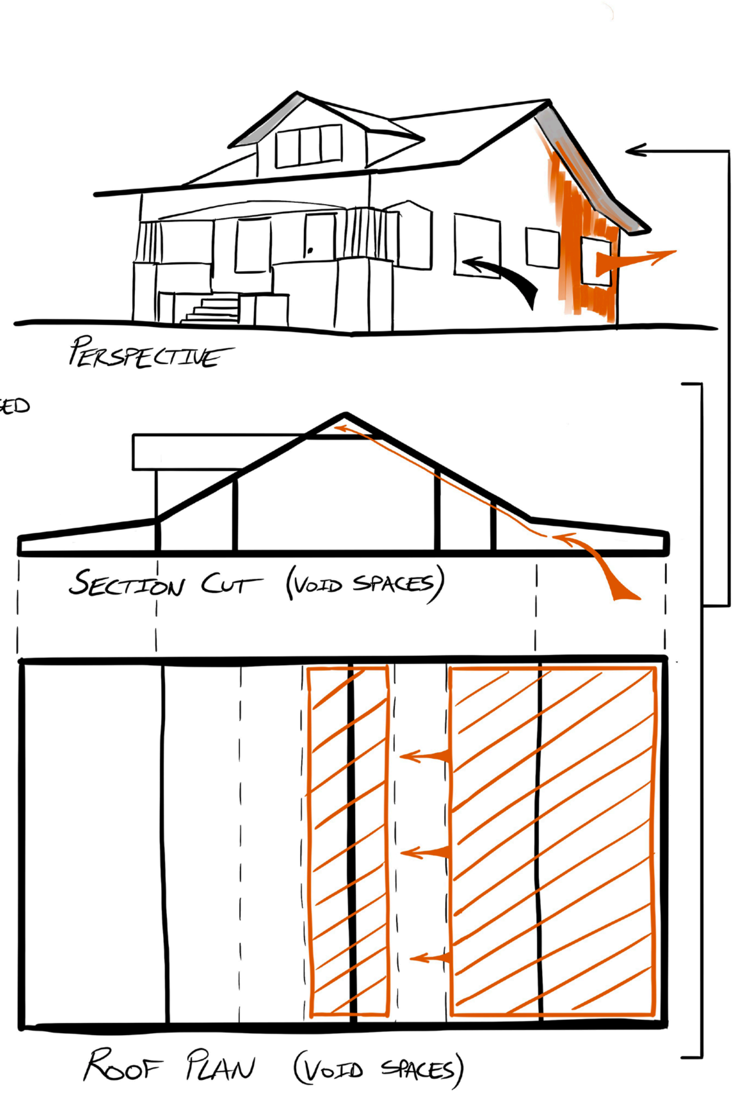


Figure 6.3 Constructing the "messy diagram." Jordan C. Legan illustration.





Step 4: Add color and relevant information. A rapid perspective, section cut, or roof plan can be helpful to explain the situation, structure, firefighters' actions, and fire spread, among other things.

Necessary Tools: Paper (notebook or dry-erase board), three markers (black, gray, orange). It is helpful if the markers have both a fine and wide tip. In lieu of traditional methods, an iPad with Procreate © software installed can be used to rapidly produce "messy diagrams."

Figure 6.4 Constructing the "Messy Diagram" continued. Jordan C. Legan illustration.

6.10 Neighborhood Surveys

In *Houses Without Names: Architectural Nomenclature and the Classification of America's Common Houses* Hubka outlines a helpful method to survey houses. This "how-to" guide is a good starting point, but rapid visual acuity of the sort firefighters need to develop cannot come solely from following a checklist; rather, it needs to be include discoveries made possible by one's curiosity.[61] One can make all sorts of distinctions about houses (or any building type for that matter) and investigate them. This thesis advises that firefighters spend time looking closely at buildings, especially specifically houses. Observing real buildings is a "skill based on valuing acuity directed at things most people overlook."[62] John R. Stilgoe writes in Outside Lies Magic that, "explorers quickly learn that exploring means sharpening all the sense, especially sight. Seeing intently means scrutinizing, staring, narrowing the eyes, even putting one's hand across the forehead to shade the eyes in one of the oldest human gestures."[63] For firefighters, observations should be filtered through the specific wayfinding tasks. This is a way to structure one's observation and make them useful on the fireground.

What the catalog of houses does well, is help one focus one's visual inquiry, lines of questioning, and discussion. For example: *How old is this house? What is the floor plan on floor 1 (meaning, what is the configuration of the kitchen, dining room, and living room)? What is the floor plan of floor 2? Where are the bedrooms and bathrooms? Where are the stairs? What challenges does the topography present?* The possible questions are endless. The catalog serves a second, equally important purpose. It provides a picture to go with the words describing each of the types, which can be helpful because "not everyone remembers plans, and few can interpret them in a wider context."[64] A simple messy diagram of the plan type in question encourages further elaboration. It works to "jog one's memory" of past experience. It works to extend the discussion out into the future too by asking "*what if?" and "what happened here?"*

Most cities have documents explaining various parts of its architectural history. Neighborhood surveys performed by historians prove to be very helpful and many of these documents are available free online. Following Hubka's example, a good place to start, is to memorize "as a set, both the typical floor plans and the exterior facades of the houses you are likely to encounter" and then go out and look for them.[65]

To a certain extent, firefighters understand the value of looking at the neighborhoods and the houses they protect. However, firefighters must learn to probe deeper, pay attention, and follow where that attention leads. And they must document this exploration. This sort of field reconnaissance develops a discernment about the built environment that may prove useful (maybe lifesaving) at a fire when decisions have to be made rapidly and are based on what little information the firefighter can gather rapidly.

Firefighters are afforded access to buildings the general public will never have. This access is a powerful learning tool. Firefighters can make accurate predictions about the inside of buildings because they will actually get to verify their assessment *from the inside*. Hubka writes, "plan identification is clearly a skill where familiarity from careful observation and house visitation breeds expertise."[66] Every medical, public service, and fire-related call is an opportunity to test hypotheses about the floor plan.

When looking at houses, one should hold assumptions loosely. All buildings change over time, but the wood-frame houses change more than most. Hubka found that continual change is the norm, not the exception. Given that wood is a material that is easy to manipulate, even amateur builders can modify a structure. Hubka emphasizes that one should "not automatically assume that the way houses look and function today is the same as when they were built or first occupied."[67] Do not spend time trying to interpret exceptional or puzzling houses. These houses distract from the primary goal which is to identify the most-common house plan types. Hubka writes, "as a rule, it is critically important to first locate and identify the dominant house types in your survey area and then proceed to identify the secondary and tertiary types. Only when the dominant types and subtypes are thoroughly mastered" should one proceed to interpret more exceptional house types.[68]

While houses change more than other buildings, there are often recognizable patterns to those changes. For example, most houses will not significantly change the front façade. Most often, significant changes happen in the back, out of view. Hubka writes, "remember that the exteriors and the interior plans of modest houses have frequently been changed over time. Therefore, train yourself to identify the underlying, original form of the common house underneath subsequent additions and remodeling changes."[69] Look at the shapes of houses. Old houses are shaped differently than new houses.

The search for house types can be organized in a number of ways. One helpful way is by battalion or response area. Firefighters assigned to a firehouse respond to a certain geographical area. Limiting the search for house types to the first-due response area or battalion is a way to keep it manageable. Over time, this can be expanded, but these boundaries solidify the idea that only a small number of house types will be present in each response area.

Outline a survey area but start small. Organize the survey in a manner that represents what firefighters are likely to encounter. For example, firefighters may organize surveys by first-due response area or by battalion. On the preliminary reconnaissance survey, the goal is only to identify the basic house types. Most fire stations respond to a prescribed geographic area, often referred to as one's "first-due." Each response area, or "first-due," will only have 4-6 of the house types identified by the catalog of house types. Start by driving around. Then get out of the apparatus and walk around. Observations taken while driving do not have the same quality as those made while walking. The benefits of increased visual acuity are not theoretical. There are serious practical implications for improving firefighters' ability to "see" and ability to document one's observations. Look closely, question everything, and take notes. This is the simple recipe for discovery (and adventure).

6.11 Portable Solutions to Differing Problems

On the fireground, the use of the catalog of types will be limited because the primary aim is to put the fire out. Spending time to draw the house prior to engaging in fire suppression and search/rescue tasks is *not* how the catalog is intended to be used. The catalog facilitates rapid recognition of cues on the fireground because patterns of cues are readily accessible in mind, they are "activated" through pre-processing and training. It is a training tool to help increase one's ability to make accurate judgments about floor plan configurations. This ability has been shown to be holistic in character and arises from repeated confrontations with houses *before* the fire.[70] Very little learning happens during firefighting efforts.

Decisions by the initial-arriving company officer set in motion a number of coordinated firefighting and search/rescue operations. A poor assessment, or "size-up," of the house has serious consequences. Communicating accurate and concise information about the building to firefighters operating in different areas is difficult given the ambiguous information, time-pressure, and acute stress firefighters experience. Generally, the initial-arriving company officer (who supervise a number of firefighters performing tasks such as fire attack and search) can effectively coordinate the initial operations of two engines, one ladder company, and a chief. This limited span of control coincides neatly with the capacity of human working memory (WM) under stress. Beyond the first "2-1-1" in Seattle jargon, the brain has reached its WM capacity and an external memory aid such as a "command board," can be helpful.

Image 6.5 Seattle Fire Department Battalion Chief buggy in-cab "command board" setup. Jordan C. Legan photo.

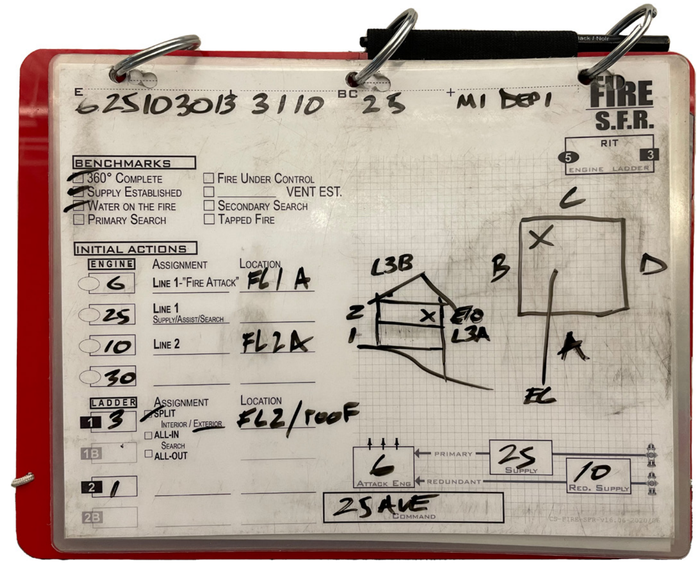


Image 6.6 An example of the "command board." Jordan C. Legan photo.

In the United States, Incident Command (a function generally assigned to chief officers, but in some agencies Captains and Lieutenants fulfill the position) supervise operations on the fireground (from the outside) and keep track of where firefighting crews are deployed and operating. Using the descriptive information heard on their radio plus their assessment from the outside of the building (the house), Incident Command (or their aide) often creates static sketches and simple diagrams of operations using varying shorthand methods.

These sketches are used to track personnel and coordinate operations. These sketches typically indicate "where firefighters are" and little else. The sketches made by chief officers are primarily 2-D representations of a building's outline with marks denoting where people and equipment are deployed (see Image 6.4). Little to no graphic training is provided to firefighters who create these sketches even though graphic representations are a powerful sensemaking tool. Some training would make these representations more functional, faster to produce, and better capture features of the scene.

According to Karl Weick, "sensemaking is about labeling and categorizing to stabilize the streaming of experience. Labeling works through a strategy of differentiation and simple-location, identification and classification, regularizing, and routinization (to translate) the intractable or obdurate into a form that is more amenable to functional deployment."[71] Diagrams are a useful tool on the fireground for Incident Command as they establish common reference points and a common language for describing features of the house, especially the floor plan. Sensemaking in this context is fundamentally about conveying information.

The catalog of house types is first and foremost a study tool that should be part of the training of firefighters, but it can also be understood as a collection of "cue cards" that can also be used by the on-scene commander to help one produce a diagram unique to the building on fire. The effectiveness of the catalog comes from how messy diagrams rapidly convey and translate spatial information to firefighters similar to the way plan, section, and elevation do for architects and the construction trades. The ability to quickly construct a representative image of a house (in two and/or three dimensions) in mind or on paper helps to clearly articulate paths of fire spread, smoke movement, wayfinding landmarks, and routes of circulation in a way that words or photos cannot.

Image 6.7 Historic image of the BSPP graphic artists producing an "operational drawing (OD) for the incident command staff at the command post.[84]

For example, the "operational drawing (OD)" in Brigade de Sapeurs-Pompiers de Paris (BSPP) jargon, is a diagram that does more than a photo or words can – "it sorts, ranks, aids the making of a diagnosis, and makes seen what is important" for successfully conducting firefighting operations.[72] The BSPP has graphic artists on staff to help commanders *make sense* of the fire (see Image 6.5).

Diagrams, like those currently produced by the BSPP, are a tool of thought and action. Given ambiguous and sometimes dangerous situations, Anne Dietrich et al., writes in "Operational Drawings for the Paris Fire Brigade: The Improbable Story of an Organizational Resource," that it serves as "a graphic medium for 'seeing to it that everyone had the same image; and in this occupation where everyone is rushing about and no one has the time to make a long explanation, a sketch is actually the surest vector for conveying information."[73] Creating these drawings in a few minutes or less requires a "mastery of the rules of engagement" – including both basic drawing convention and operational knowledge.[74] This skill can be taught and used effectively.

The "messy diagram" as proposed by this thesis, is similar to the BSPP's "operational drawing (OD)" in that it is a framework for a dynamic 2-D *and* 3-D representation forming a practical dialogue between the fire, the building, and the fire department tactics. Graphic representations produced by BSPP artists are a powerful visualization tool that conveys the vertical dimensions of the building on fire in a way the American two-dimensional representations do not (see Image 6.6). The vertical dimension of fire spread is often overlooked by firefighters.

For those not trained to think in these terms, the drawings bring to life what firefighters come to know through first-hand experience, but are often not able to articulate. This aspect of drawing as a firefighting tool is clearly shown in ODs produced during the massive

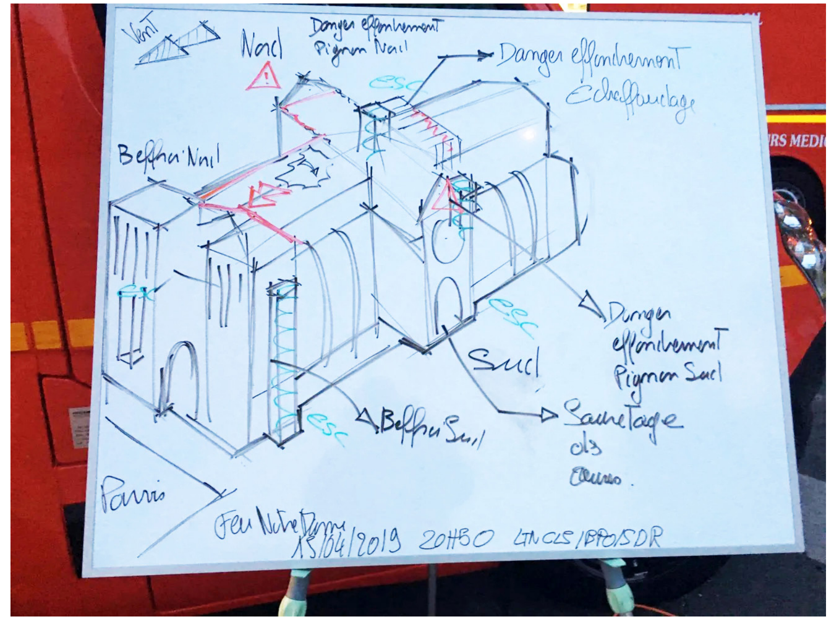


Image 6.8 Initial Operational Drawing produced during the April 15, 2019 Notre-Dame de Paris fire. Laurent Clerjeau drawing.

2019 fire at the Notre-Dame de Paris Cathedral, in Paris, France. The ODs created by the BSPP artist Laurent Clerjeau (and others) played a pivotal role in helping to direct fire suppression interventions to save this irreplaceable piece of world history from fire. The cathedral is part of the World Heritage site *Paris, Banks of the Seine*. These graphic representations show how "messy diagrams" bring out elements of the scene that cannot be "seen" easily and make it possible to understand how the fire is developing. The OD represents the rapid synthesis of field reconnaissance that has proven to be very useful to the BSPP. The OD, as an integration of *architectural features* (such as massing, structure, and void space, among others) and the *situation,* uses two- and three-dimension graphic conventions such as plan, elevation, section, perspective, notes (or callouts), and color. The format of the OD allows firefighters to conjure a similar mental image and make decisions in a more informed way than is possible with a static photo or with words.

No technology can make inferences of the sort the human brain can. It cannot distinguish between essential and distracting information, nor can it "see through walls." Sketches like the OD, maintain their utility in the "message" they convey. The OD is able to convey essential information rapidly, in stressful situations, where firefighters have no more than a few seconds to scan before they have to act because of its simplicity. Representations of the sort used by the BSPP have a basis in architecture. They elucidate how fire and smoke propagation are a function of the geometry of a building. Architecture can be thought of as a collection of structural patterns and it is the articulation of these patterns (structural and spatial) that determine where the fire will go and how quickly it will travel. Most-importantly, messy diagrams like the OD, are a tool for sharing firefighting knowledge, experience, and "know-how" *a posteriori*.

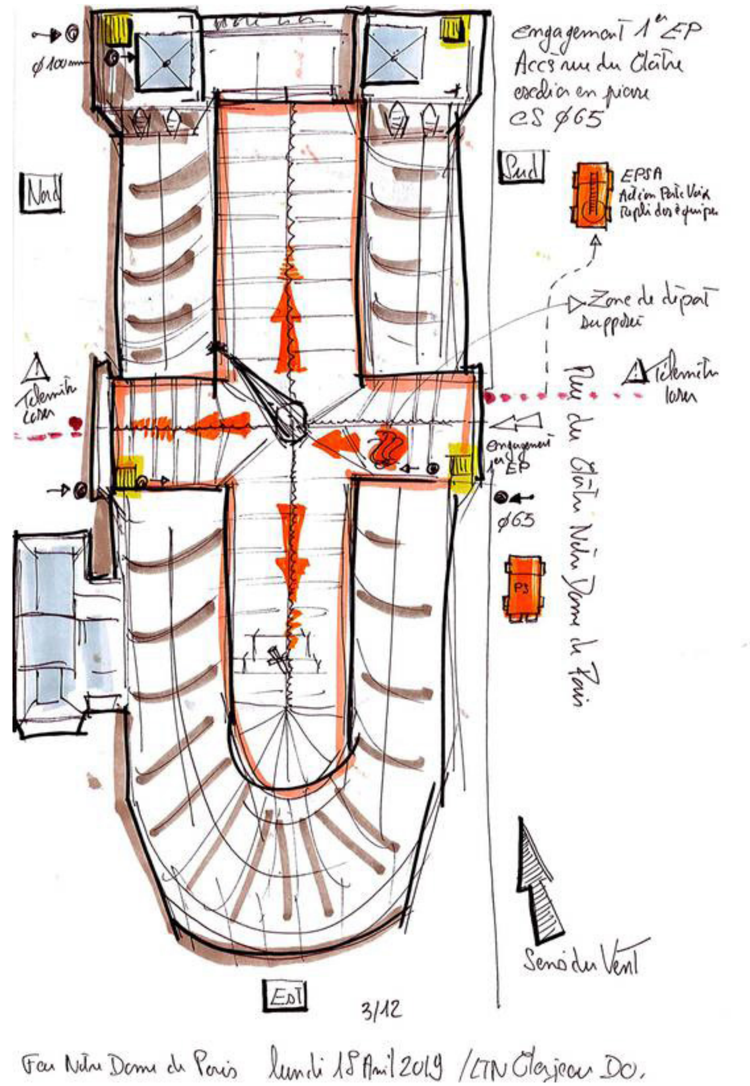


Image 6.9 Operational Drawing (Plan) produced during the April 15, 2019 Notre-Dame de Paris fire. Laurent Clerjeau drawing.[85]

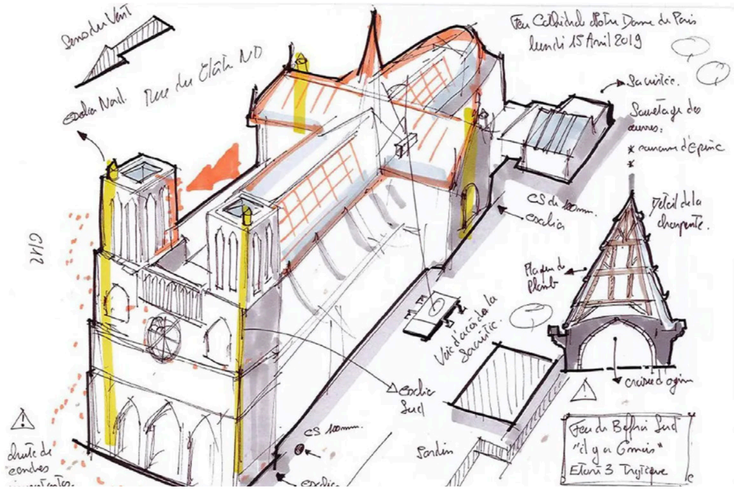


Image 6.10 Operational Drawing (Perspective and Detail) produced during the April 15, 2019 Notre-Dame de Paris fire. Laurent Clerjeau drawing.[86]

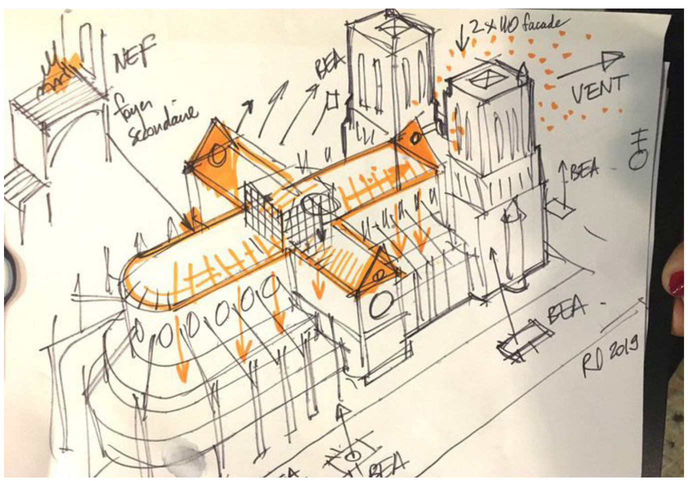


Image 6.11 Operational Drawing (Perspective) produced during the April 15, 2019 Notre-Dame de Paris fire. Laurent Clerjeau drawing.[88]

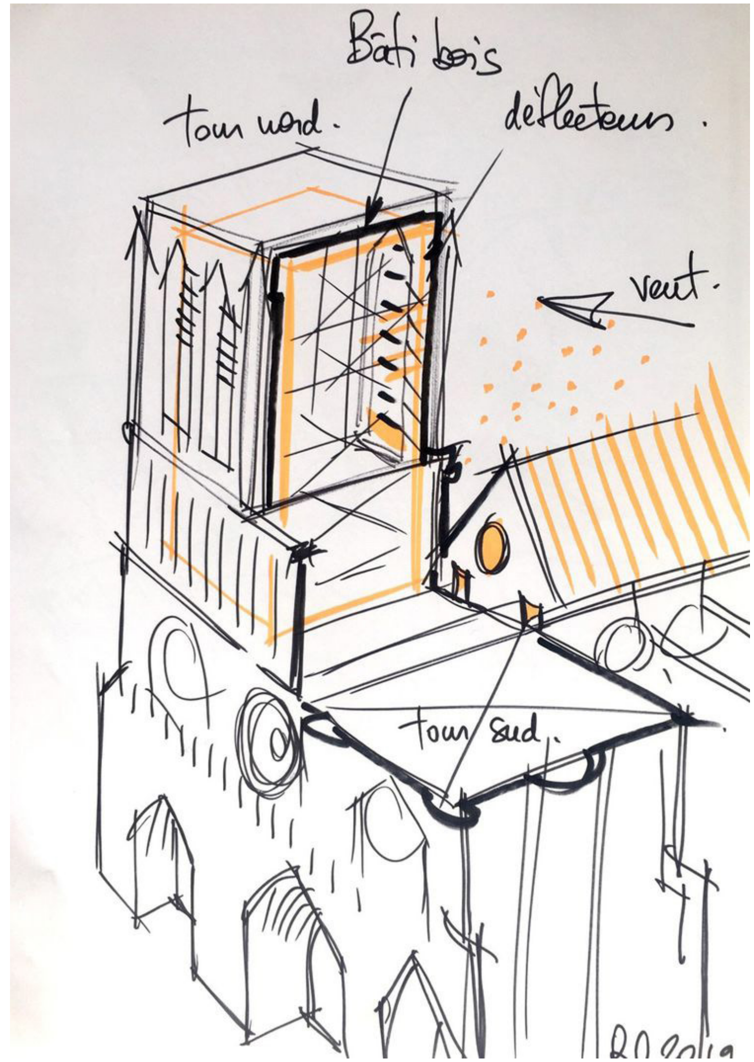


Image 6.12 Operational Drawing (Section Cut and Perspective) produced during the April 15, 2019 Notre-Dame de Paris fire. Laurent Clerjeau drawing.[87]

For the firefighters tasked with fighting the fire directly or with searching the house to locate victims, the catalog of house types (and the associated "messy diagram") will be effective in "pre- and post-processing" the built environment but it will likely have limited direct use on the fireground. During the fire, previous practice using the catalog can support the creation of a "spatial mental model." The "messy diagram," which functions as a crude "map," in which the firefighter integrate "nonindexical information (what the map tells them to expect)" and "indexical information (what they actually see)" is a wayfinding tool that currently does not exist in firefighters' toolboxes.[75] Wayfinding is a constant process of comparing one's position against the "map," whether it is by feel or in one's mind's "eye."[76] When framed in this context, the catalog is a wayfinding (and fire suppression) tool firefighters can put to use immediately.

6.12 Improving How Firefighters Share Knowledge

The lack of historical records and academic research into firefighting practice and the domain-specific expertise that firefighters have may be partially attributed to the deliberate reluctance of members to speak about firefighting experience to outsiders, especially those in academia. There is a similar reluctance to write anything down. Similar to historical craft guilds, one may say that firefighters fiercely guard their "secrets" and are selective about sharing. Equally plausible is that firefighting knowledge is difficult to articulate because the routines of expert firefighters are largely unconscious and, thus, very difficult to describe, let alone illustrate. The proposed catalog can be used as a prompt to help firefighters recount spatial features while helping the firefighters focus on where critical wayfinding decisions are made and elaborate on the structure and cognitive processes behind their experience.[77]

Firefighters routinely discuss their experience after the fire. The catalog of house types can provide firefighters a common framework to share and discuss firefighting experiences with one another. The catalog of types can be used to supplement stories firefighters tell – informally during conversation in the kitchen, or more formally in de-briefing or in a "hot-wash," the fire service term for a discussion about operations immediately after the fire, while on scene. The catalog and the messy diagrams can also be used back at the fire station or on the training ground to facilitate learning, understanding, and knowledge transfer. An illustration of the house from the catalog would serve as the initial "template" of the house in the story, one that can be altered as necessary using the "messy diagram" method. The forms of communication advocated for by this thesis facilitate rapid associations and a location where disparate information can be assembled and interpreted quickly. The "messy diagram" based on the catalog serves as a reminder of past action, something that can be examined postmortem. With words, one has a chance to re-work, erase, retell, and forget. Drawings are a record of inquiry, more stable than words. Without a standard method of communication, valuable lessons and experience are lost.

The catalog establishes a common ground for firefighters to discuss their experiences with the purpose of orienting one to salient features of the house in order to help prevent one from becoming lost. Ultimately, the catalog is a tool that supports existing storytelling practices by firefighters and helps clearly describe the setting, or "place," where firefighting practices happens. When the house corresponds to a specific type, the conversation becomes easy. When it does not, the conversation can be directed toward specific cues illustrating what was seen or missed, usually the details – was the house altered or was it built with an unconventional design? Learning occurs when one's expectations are challenged or violated.

While the structure of firefighters' memory and decision-making processes are not widely studied by scholars, it is clear that knowledge and skill are acquired over the course of many hours of practice and emergency experience. Over time, firefighters develop mental models that allow them to recognize patterns of cues, expectancies, goals, and typical actions. According to Ross et al., "mental models include both contextualized technical information and cause-and-effect relationships, which vary from domain to domain."[78] The keen intuitive ability that is credited to experts "is in fact the process of rapidly integrating information from a large array of accumulated experiences to size-up a situation and select a course of action through mental simulation."[79] Novice firefighters do not have well-developed mental models, but they are exposed to these mental models by watching experienced firefighter perform during training and on the fireground. They also hear listen to accounts of firefighting practice in the stories experienced firefighters tell.

The catalog of house types can be used to organize the environment firefighters operate in most-often and make it more intelligible. It gives firefighters something firm from which to begin learning about the neighborhood or city they serve and the houses they will be asked to wayfind inside. If firefighters are taught to identify the types of houses with respect to their spatial configurations and their associated patterns of cues, as illustrated in the catalog, then their primary work environment will no longer appear "as an undifferentiated collection" of houses.[80] The catalog is a starting point for a common way of looking at houses, documenting local conditions, illustrating firefighting "know-how," and for improving how knowledge is shared between different generations of firefighters.

6.13 Conclusion

Much of a firefighter's training is geared toward making rapid decisions. Psychomotor skills are practiced over and over, to the point that many become unconscious, or automatic. Almost no time is spent developing visual acuity or practicing a diagrammatic "shorthand" (i.e., field notes) to record observations, experience, facts, questions, inferences, and the like. And little time is spent developing a common language of terms to describe houses and their different spatial configurations in plain language.

Even with a long history of incremental improvements, firefighting practices are still not standardized throughout the United States; they vary widely between generation of firefighters and throughout different regions. Building a body of knowledge that is transferable beyond the fireground and kitchen table is necessary because so little information about firefighting experience is written down. The catalog of house types creates a common verbal and visual vocabulary and "cue cards" that can be used *before*, *during*, and *after* the fire. By fostering the adoption of a common terminology and a consistent frame of reference for firefighters, the catalog will help address some of the problems firefighters have in training, in transmitting knowledge, and in growing firefighting expertise. The catalog exponentially increases firefighters' "potential storehouse" of possible solutions to problems they may be called to solve – as it gives firefighters the ability to respond to a building pattern or environmental stimulus and improvise, if necessary.[81] The catalog will address some problems in firefighting practice, mainly how firefighters are taught to scrutinize houses and how valuable firefighting experience is transmitted to other firefighters. Due to its simplicity, the catalog may also improve the quality of reporting, record keeping, and training models allowing firefighters to train on specific types of houses.

The catalog of house types is meant to be a guide helping firefighters gain experience with the houses they will fight fire inside in a structured way. Experienced firefighters have a rich knowledge base of visual patterns of cues related to buildings on fire, but it is often idiosyncratic and difficult to articulate. Weick explains that "to share understanding means to lift equivocal knowledge out of the tacit, private, complex, random, and past to make it explicit, public, simpler, ordered, and relevant to the situation at hand."[82] The catalog of house types offers a method to extract (and document) firefighters' tacit knowledge, expertise, and "know-how" – to bring it out into the open to study and learn from.

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CONCLUSION

"The very word 'lost' in our language means much more than simple geographical uncertainty; it carries overtones of utter disaster."[1]

– Kevin Lynch

Conclusion

Over time, firefighters have compiled a unique body of knowledge about fire, cities, and buildings, but this knowledge is difficult for firefighters to articulate and difficult for researchers to examine. It seems to evade words. Through repeated experience in burning buildings, especially houses, firefighters develop a highly discriminating appreciation for subtleties of an environment few others will ever experience. Firefighters develop numerous decision trees for particular circumstances and constantly fight the tendency to become anchored in snap judgments. But firefighters must be taught that what they experience is actually a construction – one made up of multiple percepts, memories of past experiences – some of it accurate and some of it patently false. One constant, however, is that their knowledge and memories of experience are often tied to specific places. The proposed catalog illustrated in Chapter 5, demonstrates that the most-common types of houses can be given descriptive names, quantified, and used to elucidate firefighting knowledge. The catalog places, or situates, firefighters' wayfinding in smoke experience and know-how. It functions as a mnemonic.

In smoke, a firefighter's brain cannot rely entirely on the visual system to confirm information one "sees." The catalog can help fill cognitive gaps with reliable information *before* firefighters step inside. There, the catalog can serve as a template for expectations — as a navigational aid — for wayfinding inside burning houses. The catalog focuses a firefighter's finite attentional resources on what matters — the relationship between external shapes and internal spaces. It puts highly descriptive names to the most-common houses. These names prompt mental imagery that helps firefighters orient to salient features of the environment. The simple graphic representations of house types assist firefighters in recognizing, interpreting, recalling, and discussing houses using simple language based in shapes and patterns.

Firefighters' stories offer powerful memory aids and teaching tools. These stories are also experienced as a method of vicarious learning – the kind of learning that takes place through the sharing of individual and collective knowledge and experience. Found within these stories are sequences of place names and actions, which together, constitute a series of directions.[2] In firefighting, orientation and navigation skills and related environmental knowledge are passed on orally from one generation to the next, when newly trained firefighters listen to and observe more experienced firefighters. Wayfinding in smoke has to be learned and then practiced. Storytelling is a form of focused practice and a method of low-risk experimentation that connects emotion, context, relevance, and experience with valuable details about an environment in ways no other form of communication can.

At a fire, the human brain performs complex feats of mental gymnastics to quickly make sense of the situation. Complicated physiological processes, which include vision and memory, underpin this ability. The human nervous system has evolved to take in an overwhelming amount of information and sort it according to fine distinctions — using chunks and schema. When a firefighter crosses the threshold of a house on fire and steps into the smoke, their brain will have woven together an elaborate plot based on immediate perceptions and memories of previous experience in an attempt to draw connections between *things that happen* and *things that matter*. It seeks answers to the question — ***"what happened here?"***[3]

Wayfinding in this environment relies on the dynamic relationships between sensation, perception, and cognition; between memory and forgetting, and orientation and navigation. One's ability to make accurate predictions, or "educated guesses" about any environment is contingent on recognizing known features of the environment. The catalog of house types emphasizes the universal characteristics of house types, rather than the particulars. It functions as a tool to help firefighters recognize patterns of cues and as a scaffolding to consolidate new and existing knowledge, and access information from memory. It helps separate the essential and distracting information related to wayfinding in smoke. Through training, one develops the ability to refine these skills and communicate the experience to others.

Wayfinding in smoke cannot be outsourced. Technology such as thermal imaging cameras (TICs) have proven very helpful but are often cost prohibitive. However helpful, no technology, be it improved protective equipment or thermal imaging technology can replace firefighters' perceptual and cognitive abilities – the intuition that develops as a result of intimate encounters with buildings on fire. Firefighters must learn the structural and spatial organization of buildings because it is information that may save their life, or those they have sworn to protect.

Future Implications

The catalog advocates for a taxonomy that classifies houses by "internal (plan) and external (form) characteristics" which allows firefighting experience to be communicated easily and in plain language.[4] It may be useful to the fire service in multiple ways. A few specific examples stand out:

First, Chapter 1 pointed out that there currently exists no way for firefighters to definitively know their current practices are effective or how training can be improved. In 2016, a group of firefighters created a voluntary online reporting platform called the Firefighter Rescue Survey (FRS) to document how many, where, when, and how civilian victims are rescued from inside houses.[5] Their survey is a voluntary reporting mechanism that has begun to shed light on an area of the fire problem neglected by the United States Fire Administration (USFA). According to the FRS in 2021, there were 2,173 civilians rescued by firefighters in the United States.[6] Because the survey is voluntary and used only by a small fraction of fire departments nationwide, this is a gross undercount of the actual number. Every day, firefighters rescue civilians from inside houses on fire – but no one knows exactly how many. The data do begin to demonstrate where victims are likely to be found, however. According to an initial analysis of the first 2000 rescues, the FRS website states:[7]

- 60% of victims were found in houses, including mobile homes.
- 57% were found on Floor 1 and 30% were found on Floor 2.

- 45% of victims were found in bedrooms.
- 15% of victims were found in "family rooms."
- 10% of victims were found in a hallway.
- 9% of victims were found in uncategorized places (labeled "other," laundry, garage, stairs)
- 8% of victims were found in the kitchen
- 6% of victims were found in the bathroom.
- 3% of victims were found on a balcony, porch, or deck.
- 3% of victims were found in a foyer.
- 1% of victims were found in basement.

Knowing where particular rooms are located in common houses can be an important step in guiding firefighters to victims trapped in them. If firefighters know where the bedrooms are, they are likely to find victims more quickly than through an exhaustive search of other rooms. The catalog informs the "educated guesses" firefighters' make, thus allowing firefighters to focus their efforts on the victims' most-likely locations, because their survival depends on it. In a training application, the FRS dataset includes the address where each recorded rescue took place. After a fire event, using Google Earth, or a similar platform, the address of the reported rescue can be cross-referenced with the catalog of house types to allow firefighters, who did not participate in the rescue, to conjure a more accurate picture in mind. In this way, data captured by the FRS *and* the catalog can be instructive. Used in this context, the catalog becomes a vehicle for discussion on the drill ground or at the kitchen table.

Second, the fire service lacks a clear and consistent language that describes house types. Regional and generational jargon within the fire service industry causes problems because the same buildings are not uniformly defined or described. There exist no standardized names to refer to house or room types, for that matter. This is evident in the FRS data above and is also evident in the responses to the "Wayfinding in Smoke" survey administered by this author. The catalog advocates using a naming convention based on Thomas C. Hubka's research. This convention is a "system of naming based on distinctive internal (plan) and external (form) characteristics)."[8] The building trades use a graphic language of *plan*, *section*, *elevation*, and *perspective* to convey spatial information. Attaching descriptive names to places has been, and continues to be, used also by certain navigational cultures mentioned previously in Chapter 5. Place-names, as they are referred to in anthropological texts, have proven to be "durable symbols" and "indispensable aids for remembering and imagining."[9] In this context, recalling or imagining a vivid picture of the house on fire is the only way for future generations of firefighters to learn from past experience. Hubka's system can help firefighters consistently convey and understand spatial information in two- and three-dimensions. Naming is crucial to interpretation, understanding, and communication, regardless of purpose. Throughout human history, we name what we wish to remember and imagine.

Third, firefighters' memory, perceptual and cognitive faculties, and related wayfinding practices have yet to be studied. Brain science researchers who study memory could potentially use the catalog to test how firefighters' encode, consolidate, store, and retrieve memories. By using virtual reality (VR) simulators and functional magnetic resonance imaging (fMRI), the catalog may be a tool to assist researchers study firefighters' memory in a manner similar to tests performed on London taxi drivers. Additionally, the catalog might be useful to researchers who work with VR and electroencephalography (EEG) to understand wayfinding behavior in architectural space.

Fourth, the catalog is a tool that can be used by organizations such as the United States Fire Administration (USFA), the U.L.'s Fire Safety Research Institute, and evolving Firefighter Rescue Survey (FRS) to gather qualitative and quantitative data about the houses firefighters fight fires in. Additionally, the catalog may be used locally by fire departments to improve communication – enhancing pre-incident knowledge and familiarity, on-scene communication, post-incident analysis, and record-keeping. The catalog also offers a means to expand firefighting and architectural history and historiography. It allows for the creation of a more accurate and inclusive narrative about houses, including fire and firefighting interventions in documented histories of the built environment.

Lastly, and most-easily attainable, this thesis can be used as a template to expand the catalog to include other building types (i.e., rowhouses/townhouses and apartment buildings). It can be incorporated into a training curriculum. The catalog can be used to structure firefighter training, from specific drills to the construction of training props. It could even shape the designs of future firefighter training facilities to reflect the actual environment firefighters operate in. It has utilitarian range. For example, implementing a visual inquiry program using the catalog into firefighting training has far-reaching implications at all levels of firefighting organizations – from the newest firefighter to the most-senior – and it is testable. The catalog provides a means to quantify wayfinding skill and practices and train on certain wayfinding sequences (for example, orienting to the kitchen-dining-living room sequence in the standard bungalow plan or performing window-based search practicing firefighters' mental rotation skills). The catalog outlines a system to distill down essential aspects of the most-common types of houses in the United States – to understand the underlying logic behind their spatial organization, and practice attending to it. Think of the catalog as a systematic method to triage houses. It reduces a wide variety of firefighting problems down to a narrow set of life-saving heuristics (i.e., cues, expectancies, goals, and typical actions).[10] Which allows for flexible, rather than rigid, rule-bound intervention. As an educational tool, the catalog shortens the distance between known points, all of which can be broken down into their component pieces, linked together, studied, and communicated. It connects research from other fields with firefighting knowledge and experience. The catalog is a versatile tool that currently does not exist within the fire service. As such, there may be unanticipated uses different than the ones outlined in this thesis. Tools are meant to be used. This is a tool in the fullest sense, one intended to be used in the field, scrutinized, expanded, "worked over," and passed on with notes scribbled in the margins – just like any *field guide* worth its weight.

I have written this thesis as a firefighter and as a trained architect. In the endeavor, I have learned much about myself and these chosen professions. I have inquired about their academics, their histories, and with this document attempted to better their futures. Most of all, I have written seriously of houses, of fires, and of smoke eaters, with the hope that it might help firefighters locate those lost in dark smoke – *faster*. Perhaps author Kurt Vonnegut sums up the social contract upheld by firefighters best when he wrote, "I can think of no more stirring symbol of man's humanity to man than a fire engine."[11] Every day specially trained people stand watch in firehouses across the United States, willing to offer their life up as collateral for another because this vocation cannot exist solely in theory, in memory, or in stories. When the bell rings signaling a fire, the lost expect their firefighters to know where to look to bring them home.

Sheri Hemrick photo.

ENDNOTES (Conclusion)

1 Kevin Lynch, *The Image of the City* (Cambridge: The MIT Press, 1960), 4.

2 Michael Bond, *From Here to There: The Art and Science of Finding and Losing Our Way* (Cambridge: The Belknap Press of Harvard University Press, 2020), 12.

3 Keith H. Basso, *Wisdom Sits in Places: Language and Landscape Among the Western Apache* (Albuquerque: University of New Mexico Press, 1996), 6.

4 Thomas C. Hubka, *Houses Without Names: Architectural Nomenclature and the Classification of America's Common Houses*. First ed. Vernacular Architecture Studies Series. (Knoxville: University of Tennessee Press, 2013)

5 "About," Firefighter Rescue Survey website, accessed April 30, 2022, http://www.firefighterrescuesurvey.com/about.html.

6 "About," Firefighter Rescue Survey website, accessed April 30, 2022, http://www.firefighterrescuesurvey.com/about.html.

7 "The First 2000," Firefighter Rescue Survey website, accessed April 30, 2022, http://www.firefighterrescuesurvey.com/the-first-2000.html.

8 Hubka, *Houses Without Names,* foreword.

9 Basso, *Wisdom Sits in Places,* 7.

10 Karol G. Ross, James W. Lussier, and Gary Klein, "From the Recognition Primed Decision Model to Training," in *The Routines of Decision Making*, ed. Tilmann Betsch and Susanne Haberstroh (New York: Psychology Press, 2012), 330.

11 Allison Donahue, "Vonnegut's Firefighters," The New Inquiry, last modified September 11, 2011, https://thenewinquiry.com/vonneguts-firefighters/.

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2.4 - The Fitts and Posner Stages of Motor Learning

Source: Philip Alexander Furley and Daniel Memmert, "The Role of Working Memory in Sport," International Review of Sport and Exercise Psychology 3, no. 2 (2010): 179.

2.5 - Fire Department Training Facility

Source: Jordan C. Legan photo.

2.6 - Fire Department Training Facility

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Source: Sheri Hemrick photo, personal email to author, 2019.

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Source: Sheri Hemrick photo, personal email to author, 2019.

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Source: Alfred L. Yarbus, *Eye Movements and Vision* (New York: Springer, 2013), 174.

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4.9 - Egocentric vs. Allocentric Navigation

Source: Ekstrom, et al.,"Interacting Networks of Brain Regions Underlie Human Spatial Navigation: A Review and Novel Synthesis of the Literature," 3335.

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Source: Drawings reproduced by Jordan C. Legan. Thomas C. Hubka, *Houses Without Names: Architectural Nomenclature and the Classification of America's Common Houses*. First ed. Vernacular Architecture Studies Series. (Knoxville: University of Tennessee Press, 2013), 53-54.

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Source: Drawings reproduced by Jordan C. Legan. Thomas C. Hubka, *Houses Without Names: Architectural Nomenclature and the Classification of America's Common Houses*. First ed. Vernacular Architecture Studies Series. (Knoxville: University of Tennessee Press, 2013), 55-56.

5.7 - Early-Modern Prototypes

Source: Drawings reproduced by Jordan C. Legan. Thomas C. Hubka, *Houses Without Names: Architectural Nomenclature and the Classification of America's Common Houses*. First ed. Vernacular Architecture Studies Series. (Knoxville: University of Tennessee Press, 2013), 57-58.

5.8 - Modern Prototypes

Source: Drawings reproduced by Jordan C. Legan. Thomas C. Hubka, *Houses Without Names: Architectural Nomenclature and the Classification of America's Common Houses.* First ed. Vernacular Architecture Studies Series. (Knoxville: University of Tennessee Press, 2013), 59-60.

5.9 - Modern Prototypes Continued

Source: Drawings reproduced by Jordan C. Legan. Thomas C. Hubka, *Houses Without Names: Architectural Nomenclature and the Classification of America's Common Houses.* First ed. Vernacular Architecture Studies Series. (Knoxville: University of Tennessee Press, 2013), 60.

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Source: Laurent Clerjeau drawing. “Notre-Dame – Dans la peau du dessinateur opérationnel,” Allo Dix Huit website (official magazine of the Paris Fire Brigade), accessed May 10, 2022, https://allo18-lemag.fr/notre-dame-dans-la-peau-du-dessinateur-operationnel/.

6.9 - BSPP Operational Drawing (Plan View)

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Source: Laurent Clerjeau drawing. “Scenes from a firefigher’s notebook,” New Zealand Herald website, accessed May 5, 2022, https://www.nzherald.co.nz/world/scenes-from-a-firefighers-notebook/7AMLIGZ3L2ZZYAGXN3KJKPFGNE/.

6.11 - BSPP Operational Drawing (Perspective)

Source: Laurent Clerjeau drawing. “Le dernier secret de l’incendie de Notre-Dame.” LesEchos website. Accessed May 4, 2022. https://www.lesechos.fr/politique-societe/societe/le-dernier-secret-de-lincendie-de-notre-dame-1139276.

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Source: Laurent Clerjeau drawing. “Le dernier secret de l’incendie de Notre-Dame.” LesEchos website. Accessed May 4, 2022. https://www.lesechos.fr/politique-societe/societe/le-dernier-secret-de-lincendie-de-notre-dame-1139276.

Conclusion

Photo - Training Fire

Source: Sheri Hemrick photo, personal email to author, 2019.

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