Richmond Journal of Law and Technology

Volume 16 | Issue 4 Article 3

2010

Fire Pattern Analysis, Junk Science, Old Wives Tales, and Ipse Dixit: Emerging Forensic 3D Imaging Technologies to the Rescue?

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FIRE PATTERN ANALYSIS, JUNK SCIENCE, OLD WIVES TALES, AND *IPSE DIXIT*: EMERGING FORENSIC 3D IMAGING TECHNOLOGIES TO THE RESCUE?

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Cite as: Thomas R. May, *Fire Pattern Analysis, Junk Science, Old Wives Tales, and Ipse Dixit: Emerging Forensic 3D Imaging Technologies to the Rescue?*, XVI Rich. J.L. & Tech. 13 (2010), http://jolt.richmond.edu/v16i4/article13.pdf.

INTRODUCTION

[1] Forensic science is undergoing a period of transformation as legal and scientific forces converge and force older forensic sciences toward a new scientific paradigm.[1] Fire investigative undertakings are not an exception to this trend. Skeptical defense attorneys who routinely formulate astute *Daubert* challenges to contest the scientific validity and reliability of every major forensic science discipline are one catalyst to this revolution. Furthermore, a steady influx

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[1] *See* Michael J. Saks & Jonathan J. Koehler, *The Coming Paradigm Shift in Forensic Identification Science*, 309 SCIENCE MAGAZINE 892 (2005) *available at* http://www.sciencemag.org/cgi/reprint/ 309/5736/892.pdf; *see also* Paul C. Giannelli, *Forensic Science: Under The Microscope*, 34 OHIO N.U. L. REV. 315, 315 (2008); National Research Council et al., *Strengthening Forensic Science in the United States: A Path Forward* 72, http://www.nap.edu/openbook.php?record_id=12589& page=R1 ("Under the General Forensics R&D Program, 53 awards have been made through 2007 for the development of "tools and technologies that will allow faster, more reliable, more robust, less costly, or less labor-intensive identification, collection, preservation, and/or analysis of forensic evidence; tools that provide a quantitative measure or statistical evaluation of forensic comparisons; and identification or characterization of new analytes of forensic importance.") [hereinafter STRENGTHENING FORENSIC SCIENCE].

of novel scientific advances makes possible the formulation of consistent and scientifically-based quantitative forensic evidence analyses to overcome the "undervalidated and oversold" problems affecting many areas of forensic science.[2]

[2] Fire pattern analyses are utilized in fire and arson investigations and consist of analytical methodologies based on expert interpretation of discernable patterns enduring after a fire event.[3] These interpretive techniques, however, have long been plagued by "ill-defined, flexible, and explicitly subjective criterion"[4] based upon unproven assumptions, exaggerated claims, and deficient research, testing, and measuring techniques.[5] Although fire investigations sometimes employ quantitative objective measurement techniques, none sufficiently elevate fire investigations to the status of a scientific discipline.[6] The improper application of broadly disseminated misinterpretations by an undereducated fire investigative community adds fuel to the forensic validation fire. In fact, fire pattern analysis has recently been the subject of intense public scrutiny, with some claiming that testimony based upon faulty fire pattern interpretation may have contributed to wrongful convictions and the execution of innocent persons.[7]

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[2] *See* William A. Tobin & William C. Thompson, *Evaluating and Challenging Forensic Identification Evidence*, 20 CHAMPION, Jul. 2006, at 12.

[3] *See* Natl. Fire Protection Assoc., *NFPA 921 Guide for Fire & Explosion Investigations* (2008) (*hereinafter* NFPA 921) at 3.3.60 ("Fire Patterns. The visible or measurable physical changes, or identifiable shapes, formed by a fire effect or group of fire effects.").

[4] *See* EDWARD J. IMWINKELRIED, THE METHODS OF ATTACKING SCIENTIFIC EVIDENCE 204 (4th ed. 2004); Michael J. Saks, Jonathan J. Koehler, *The Individualization Fallacy in Forensic Science Evidence*, 61 VAND. L. REV. 199, 200 (2008).

[5] *See generally* David L. Faigman, *Anecdotal Forensics, Phrenology, and Other Abject Lessons From the History of Science*, 59 HASTINGS L.J. 979, 979–80 (2008).

[6] *See generally* Michael J. Saks & David L. Faigman, *Failed Forensics: How Forensic Science Lost Its Way and How It Might Yet Find It*, ANN. REV. LAW SOC. SCI. 149, 149–50 (2008), *available at* http://arjournals.annualreviews.org/doi/pdf/10.1146/annurev.lawsocsci.4.110707.172303.

[7] *See* Christy Hoppe, *Some Experts Question Science in Texas Arson Cases*, CHARLESTON GAZETTE & DAILY MAIL (W. Va.), Sept. 20, 2009, at 11A ("Arson investigators in Texas have relied on old wives' tales and junk science to send men to prison, and perhaps even the death chamber, top experts on fire behavior say.").

[3] Even though the "fire investigation community is looking to improve its capabilities by building a better scientific foundation for fire investigation,"[8] "[t]oday's situation exists because the basis for identification of fire origin and cause has evolved from practical knowledge rather than scientific research."[9] Moreover, interpreting fire patterns can be extremely difficult due to factors such as "the materials burning, the building geometry and ventilation and the fire fighting actions."[10] Modeling fire growth history presents numerous issues.[11] For example, present photography methods are an inefficient capture method because the transfer of heat during a fire is not a "one-dimensional phenomena."[12]

[4] Rapid forensic technological progress related to increasingly complex fire investigations is beginning to blur the role of the fire expert and the fire investigator.[13] In spite of this, the emerging revolution in forensic 3D imaging

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[8] *See* Daniel Madrzykowski, *State-of-the-Art Research Is the Future of Fire Investigation*, SIU AWARENESS, Mar. 2001, at 19, http://fire nist.gov/bfrlpubs/fire01/PDF/f01151.pdf (last visited April 6, 2010).

[9] *See* The Fire Protection Research Foundation, *Recommendations of The Research Advisory Council on Post-Fire Analysis—A White Paper*, Feb. 2002, at 1, http://www.nfpa.org/assets/files//PDF/Research/Post-fire_Analysis_Research_Council_-_White_Paper.pdf. (last visited April 6, 2010). *Id.* at 5 ("There is a lack of scientific foundation for many methods used to identify the area of origin and the cause of fires.").

[10] *See id.* at 5.

[11] *See* VYTENIS BABRAUSKAS, SOME SPECIALIZED AREAS WHERE RESEARCH IS NEEDED, FIRE GROWTH AND SPREAD ON OBJECTS WORKSHOP, http://www.fire nist.gov/bfrlpubs/fire03/PDF/f03133.pdf (last visited April 6, 2010).

[12] *See* Natl. Fire Protection Assn., Intl. Assoc. of Arson Investigators, USER'S MANUAL FOR NFPA 921 GUIDE FOR FIRE AND EXPLOSION INVESTIGATIONS 49 (2nd ed. 2005) ("It is important to remember that fire is a three-dimensional event, and therefore fire effects [e.g. patterns] can be three dimensional.").

[13] *See generally* Paul R. Bartolacci & Georgia S. Foerstner, *From the Lawyer's Perspective: The Role of a Fire Protection Engineer in the Investigation of Fire Related Losses and Subsequent Litigation*, FIRE PROTECTION ENGINEERING (Winter 2004), at http://www fpemag.com/archives/article.asp?issue_id=13&i=65 ("Because of the heightened standard of admissibility for expert testimony, more and more fire protection engineers will need to be involved in forensic matters in order to overcome the *Daubert* challenges. For example, today, in a fire spread case, it is risky for a claimant to rely solely on a basic cause-and-origin fire investigator, with no fire protection engineering background, to give opinions on issues involving fire spread . . .") (last visited April 6, 2010).

technologies will provide solutions to remedy unreliable and subjective fire investigative and reconstruction practices.[14] The combination of technological advances in "photogrammetric measurement systems and the rapid progress in the areas of laser scanners, machine, computer and robot vision have opened the way to new applications for optical static and kinematic measurement techniques."[15] Similar advances in image processing technologies "now allow data from more than one image to be combined providing improved data for subsequent analysis."[16] Together, these new methods and technologies will revolutionize fire scene investigations.

[5] Three-dimensional-based digital imaging methodologies will replace existing 2D-based approaches in fire scene documentation and data capture. The application of materials science technology will improve both the macroscopic and microscopic examination of fire scenes.[17] Imaging processing techniques will be used to compare fire artifacts with automatically-retrieved exemplars of studied furnishing materials contained in a database that have been comparatively examined and tested. And advances in forensic visualization will allow for the communication of "highly complex, technical, spatial and temporal evidential information of incident scenes."[18]

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[14] *See, e.g.*, G. Sasse, et al., *Digital Crime Scene Reconstruction – The Evolution of the Digital Documentation to the Integral and Virtual Analysis*, http://www.dcsr.ch/images1/downloads/IAFS_Poster_2k.pdf ("The fields of application of these new procedures are altogether convincing, innovative and forward-looking—the digital revolution in solving crimes") (last visited April 6, 2010).

[15] *See* 8th Conference on Optical 3-D Measurement Techniques (Jul. 9–12, 2007) - ETH Zurich, Switzerland, http://www.photogrammetry.ethz.ch/optical3d/O3D2007_program.pdf (last visited April 6, 2010).

[16] *See* Simon Bramble, et al., *Forensic Image* Analysis, *in* 13TH INTERPOL FORENSIC SCIENCE SYMPOSIUM D4-3 (2001), http://www.interpol.int/public/Forensic/IFSS/meeting13/Reviews/Image.pdf (last visited April 6, 2010).

[17] *See* R. A. Schroeder˙ R. B. Williamson, *Application of Materials Science to Fire Investigation*, at http://www.schroederfire.com/ras_diss/ch01.htm; ("X-ray diffraction and scanning microscopy [will] be used for . . . examination . . . .") (last visited April 6, 2010).

[18] M.E. Ma, *3D Visualisation of Crime Scenes: Computer Animation in Forensics (RICF Project)*, http://www.derby.ac.uk/files/eunice_ma_-_3d_visualisation_of_crime_scenes_computer_animation_in_forensics_ricf_project.pdf (last visited April 6, 2010).

[6] This article will explore this revolution in fire scene investigation and its intersection with the law. Part I of the article will discuss the current state of the art in fire scene investigation, including its limitations and the legal issues arising from the use of insufficiently validated methodologies. Part II will examine emerging forensic imaging technologies and their application to fire scene investigations. Part III of the article will evaluate the advantages of using 3D imaging in fire scene investigations to overcome admissibility and reliability concerns.

I. FIRE INVESTIGATION

A. Current Investigative Methodologies

[7] A fire investigator is tasked to establish the origin(s) of the fire and then to investigate the cause.[19] Investigators use fire pattern analysis in an effort to follow the path, progression, and spread of fire back to its source.[20] First published in 1992 by the National Fire Protection Association (NFPA), the protocols contained in *NFPA 921: Guide for Fire and Explosion Investigations* have become the *de facto* national standard for fire scene examination and analyses.[21] Under these protocols, the fundamental purpose of conducting a fire scene investigation is to "collect all of the available data and document the incident scene."[22] Meticulous scene documentation is vital because fire investigations commonly include a "review of previous scene documentation done by others."[23] Primarily, documentation of fire patterns largely relies upon still photography.[24] In addition

[19] JOHN J. LENTINI, SCIENTIFIC PROTOCOLS FOR FIRE Investigation 118 (CRC Press) (2006).

[20] *See id.* at 6.1.1 ("the process of interpreting fire patterns to determine how the patterns were created.").

[21] *See* Guy E. Burnette Jr., *Documentation of the Fire Scene: A Legal Perspective*, http://www.interfire.org/res_file/docscleg.asp (last visited April 6, 2010).

[22] *See* NFPA 921, *supra* note 3, at 4.4.3.1.

[23] *See id.* at 4.4.3.2; *see also id.* at 4.4.3.3 ("The use of previously collected data from a properly documented scene can be used successfully in an analysis of the incident to reach valid conclusions through the appropriate use of the scientific method. Thus, the reliance on previously collected data and scene documentation should not be inherently considered a limitation in the ability to successfully investigate the incident.").

[24] *See id.* at 15.2.1.1.

to traditional investigative scene documentation techniques such as photography and sketches, other tools are available to investigators. For example, NFPA recommends that fire investigators utilize "specialized sketches and diagrams to assist in documenting specifics of the fire investigation," detailing the schematics, ". . . fire pattern, depth of char survey, depth or calcination survey, heat and flame vector analysis, and others, as required."[25] The investigator reconstructs the scene to first determine the area of fire origin by identifying and tracing movement and intensity fire patterns.[26] After this, an investigator will attempt to define a specific point of origin.[27]

[8] In contrast, forensic fire scene reconstruction entails a more comprehensive approach.[28] Forensic fire scene reconstruction accounts for more than identifiable fire pattern damage, and includes human factors such as witness accounts and tenability; forensic evidence such as fingerprints and physical injuries; and "the application of the scientific method based upon relevant scientific principles and research."[29] The investigator "traces the fire's area, growth, and direction of travel taking into account the identifiable fire patterns of smoke deposit, damage due to heat transfer, human factors, forensic physical evidence, effects of fire suppression, and a broad knowledge of case histories of similar scenarios."[30] This thorough investigative methodology is the most prudent course of action since fire investigators are expressly cautioned that burn patterns

[25] *See id.* at 15.4.5.7 (2008); *see also id.* at 17.4.2 ("Heat and flame vectoring is applied by constructing a diagram of the scene . . . through the use of arrows, the investigator notes the interpretations of the direction of heat or flame spread based upon the identifiable fire patterns present."); *id.* at 17.4.2.3 ("depth of char or depth of calcinations survey . . . results plotted on a diagram . . . measurements recorded on the diagram, lines drawn connecting points of equal, or nearly equal, char or calcinations depths. The resulting lines may reveal identifiable patterns.").

[26] *See id.* at 6.1.1.

[27] *See* NFPA 921, *supra* note 3, at 3.3.122 ("[t]he exact physical location where a heat source and a fuel come in contact with each other and a fire begins.").

[28] DAVID J. ICOVE & JOHN D. DEHAAN, FORENSIC FIRE SCENE RECONSTRUCTION, 22 (2004).

[29] *Id.* at 22–23.

[30] *Id.* at 22–23.

alone "can often be misleading and should only be used to establish origin and cause when they are unambiguous or are supported by other physical evidence."[31]

B. Fire Investigator Qualifications: An Occupation Plagued by Educational and Training Deficiencies

[9] Most fire investigators have little formal education in scientifically rigorous fire-related subject matter.[32] Fire investigation has traditionally relied upon an apprenticeship model for tutoring its practitioners.[33] Consequently, fire investigators often rely upon rules of thumb.[34] To deflect criticisms, many practitioners maintain that "the practical judgment gained through experience, is somehow superior to or at least incompatible with, the methods of science."[35] In fact, perhaps in a futile attempt to maintain the status quo, a leading fire investigative organization asserted that fire investigation was not science at all and further opined that "all non-science fields should be excused from having to prove their validity."[36]

[10] The development of Bachelor's (and even Master's) degree programs have augmented the field of fire investigation education beyond the more traditional

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[31] Richard L. P. Custer & David T. Sheppard, *Fire Loss Investigation*, *in* FIRE PROTECTION HANDBOOK, Ch. 2 § 3 (20th ed. 2008).

[32] Hoppe, *supra* note 7 ("fire investigators—who technically need only a high school education—will almost never have advanced college degrees"). *See also* LENTINI, supra note 19, at xvii (noting that fire investigators "may have no education beyond high school.").

[33] *See Summary Report for: 33-2021.02 Fire Investigators*, O*NET ONLINE, 2008, http://online.onecenter.org/link/summary/33-2021.02.

[34] Douglas J. Carpenter & Richard J. Roby, "*Training Versus Education: The Case for the Development of a National Curriculum for Fire Investigators*" in PROCEEDINGS OF THE 2ND INTL. SYMPOSIUM ON FIRE INVESTIGATIONS SCIENCE AND TECH., 485–86, (2006), *available at* http://www.csefire.com/Presentations/ISFI_Presentation_NatFireCur_DJC_Final.pdf.

[35] Russell A. Ogle, *The Need for Scientific Fire Investigations*, FIRE PROTECTION ENG., No: 8 (Fall 2000).

[36] Michael J. Saks, *Banishing Ipse Dixit: The Impact of Kumho Tire on Forensic Identification Science*, 54 WASH. & LEE L. REV. 879, 885 n. 27 (2000) (quoting Mich. Millers Mutual Ins. Co. v. Benfield, 140 F. 3d 915 (11th Cir. 1998)).

Associate's degree programs offered by community colleges.[37] Nevertheless, "[t]he relationships between the providers of training, certification, and higher education are varied across the country . . . from excellent to nonexistent."[38] The "usually uncoordinated and fragmented" educational and training efforts targeting the fire investigation community are "resulting in duplications of effort and inefficiencies for students."[39]

[11] Numerous fire investigators are ignorant to the basic principles of fire dynamics and lack the understanding and education directly applicable to fundamental theories concerning the same.[40] Typically, fire investigators learned the meaning of fire patterns through experience and training.[41] Many fire investigators continue to rely upon persistent myths and misconceptions when interpreting the significance of fire-related pattern evidence.[42] Now, however, there is greater emphasis on verifying the fire dynamics.[43] A fire investigator's ability "to use [fire dynamics] calculations is important in the application of basic fire science and engineering concepts,"[44] and is "essential in evaluating the

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[37] *See* Jerry W. Laughlin, *Training Programs for Fire and Emergency Service Personnel*, *in* FIRE PROTECTION HANDBOOK, Ch. 10 § 12 (20th ed. 2008).

[38] U.S. Fire Administration, Natl. Fire Academy, *Professional Status: The Future of Fire Service Training and Education*, *available at* http://www.usfa.dhs.gov/downloads/pdf/nfa/higher-ed/ProfStatusArticle.pdf.

[39] *Id.*

[40] *See generally* Joe M. Ellington, *Fire Dynamics and Fire Computer Modeling*, http://fire-dynamics.com/Library/Fire%20&Dynamics%20&%20Computer%20Modeling.ppt.

[41] Intl. Assoc. of Arson Investigators, *supra* note 12, at 36.

[42] *See* LENTINI, *supra* note 19, at 467 (". . . after three centuries of scientific examinations of fire, myths have been added rather than dispelled. The sheer number of misconceptions, and their widespread publication in learned and not-so-learned treatises, indicate that fire investigation, as a profession, still has very far to go.").

[43] *Id*.

[44] ICOVE, *supra* note 28, at 78.

various working hypotheses, such as how much fuel was burned, the fire's time duration, and the impact of ventilation of the room of origin."[45]

C. Fire Dynamics: An Evolving and Unsettled Discipline

[12] Fire, defined as "uncontrolled combustion involving chemistry, thermodynamics, fluid mechanics, and heat transfer,"[46] is a complex phenomenon that is "inadequately understood."[47] Fire dynamics analysis use "mathematical equations derived from fundamental scientific principles or from empirical data, [ranging] from simple algebraic equations to computer models incorporating many individual fire dynamics equations, . . . to predict fire phenomena and characteristics . . . ."[48] Fire investigators must be knowledgeable in fire dynamics "to estimate accurately a fire's origin, intensity, growth, direction of travel, and duration."[49]

[13] Research scientists and engineers have worked over the past twenty-five years to develop an understanding of the factors and physical processes that enter into and control the growth and spread of fire and its products.[50] "While fire dynamics is emerging as a scientific discipline, the complex nature of its fundamental processes, coupled with a relatively low research funding effort, account for the rather slow progress in quantifying fire behavior."[51] Moreover, "[t]he materials that make up the bulk of the fuels involved in most structure fires have changed dramatically over the last thirty or forty years, affecting the way in which fires ignite and spread, the combustion products they create, the heat

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[45] *Id.*

[46] JAMES G. QUINTIERE, PRINCIPLES OF FIRE BEHAVIOR 12 (1998).

[47] BFRL Strategic Goal: Measurement Science for Innovative Fire Protection, *available at* http://www.nist.gov/bfrl/innovative_fireprotection_goal.cfm.

[48] NFPA 921, *supra* note 3, at 20.4.8.

[49] ICOVE, *supra* note 28, at 68.

[50] *See* FIRE PROTECTION HANDBOOK (Nat'l Fire Prot. Ass'n. Richard L.P. Custer ed., 20th ed. 2008).

[51] NAT'L MATERIALS ADVISORY BD., NAT'L ACAD. OF SCIENCES, FIRE DYNAMICS AND SCENARIOS 5 (1978).

release rates and temperatures they produce, and the residues they leave behind."[52] The current body of fire dynamics knowledge is in a highly incomplete state and many years of intensive research are needed to fill in the gaps.[53]

D. Fire Patterns: Unresolved "Burning" Questions

[14] Fire patterns are the visible or measurable effects, or identifiable shapes, that remain after a fire.[54] "Most patterns are recorded on two-dimensional surfaces, at a place where those surfaces intersect with the three-dimensional

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[52] *See* John DeHaan, *Our Changing World: Fires, Fuels, Investigations, and Investigators*, *available at* http://www.interfire.org/features/ourchangingworld.asp.

[53] *See* NAT'L FIRE ACAD., APPLICATIONS OF FIRE RESEARCH COURSE GUIDE 2–13 (FEMA, USFA 1998); *see also* BABRAUSKAS, *supra* note 11 (stating that "our knowledge of the ignitability of materials from flames is exceptionally poor," . . . and . . . "[o]ur knowledge of heat fluxes generated by various burning combustibles is relatively limited.); NAT'L MATERIALS ADVISORY BD., *supra* note 68, at 4 (stating that "[m]any years of intensive research will be required to fill in the gaps, and the present level of research activity is inadequate."); JAMES G. QUINTIERE, FIRE SPREAD ON WALLS AND CEILING TO FLASHOVER, *available at* http://fire nist.gov/bfrlpubs/ flamespread/Abstract/Quintiere%20Abstract.pdf (stating that "[t]he difficulties that prevent accurate prediction [of flame spread] are the ability to resolve the reaction region, radiation heat transfer, and turbulence effects."); JAMES S. T'IEN, DETAILED MODELING OF FLAME SPREAD PROCESSES OVER SOLID: PROGRESS AND PROSPECT (presented at The Fire Spread and Growth on Objects Workshop, NIST, Mar. 4–6, 2002) (stating that "[a] spreading flame involves many interactive sub-processes: fluid flow, heat and mass transfer, solid thermal decomposition, gas-phase chemical kinetics and multi-dimensionality. To make a flame-spreading problem 'tractable' theoretically, a number of simplifying approximations are normally made. This often limits the usefulness of the [computer fire] model results.") *available at* http://www.fire nist.gov/bfrlpubs/ flamespread/Abstract/Tien%20Abstract.pdf; *Id.* (stating that "[i]nstead of treating radiation in an ad hoc way as in the past (e.g. assuming 40% of heat release is from radiation), recent effort has been to compute radiation in a more rigorous manner."). *Cf.* BARRY N. TAYLOR & CHRIS E. KUYATT, GUIDELINES FOR EVALUATING AND EXPRESSING THE UNCERTAINTY OF NIST MEASUREMENT RESULTS at iv (1994) (stating that "[i]t is generally agreed that the usefulness of measurement results, and thus much of the information that we provide as an institution, is to a large extent determined by the quality of the statements of uncertainty that accompany them."). *But cf.* Inam Intl. Inc. v. Broan-Nutone L.L.C., No. 1:05-CV-0852-CAP, 2007 WL 4730649, at *7 (N.D. Ga. Sept. 21, 2007) ("calculat[ing] the heat intensities necessary to produce the observed burn patterns . . . methodology constituted a generally accepted practice in the field.").

[54] Dennis W. Smith, *The Firefighter's Role In Preserving The Fire Scene*, 150 Fire Engineering (Jan. 1997) *available at* http://www.kodiakconsulting.com/DWSPreserve.pdf. *See also* NFPA 921, *supra* note 3, at 3.3.60.

fire."[55] "Fire patterns that record what happened during the course of a fire often provide no information of the sequence of pattern development."[56] What we see after a fire is the total record of what happened, without necessarily seeing the sequential order of the creation of each pattern."[57]

[15] The effects of smoke, hot gases, heat, and flames on materials form the fire patterns used to trace the course of the fire; reversing that process establishes the area of origin of the fire.[58] These effects can be generally categorized as:

1. Surface deposits (with no irreversible effects on substrate);
2. Surface thermal effects—scorching or melting, discoloration;
3. Charring—surface;
4. Penetration—charring below surface;
5. Consumption—charring completely through a material or actual destruction.[59]

Patterns with distinctive geometry or shape are created by the effects of fire and smoke exposure on building materials and contents.[60] While interior fires often

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[55] *See* LENTINI, *supra* note 19, at 75.

[56] *Id.* at 84.

[57] *Id.*; *see also* NFPA 921, *supra* note 3, at 17.2.3 (stating that "[t]he surfaces of the fire scene record all of the fire patterns generated during the lifetime of the event, from ignition through suppression, although these patterns may be altered, overwritten, or obliterated after they are produced. The key to determining the origin of the fire is to determine the sequence in which these patterns were produced.").

[58] *See generally* International Symposium on Fire Investigation Science and Technology, *Full-Scale Room Burn Patterns Study* (2008) (stating that "[f]ire origin determination is now, and has always been, largely a matter of fire pattern recognition and analysis."), *available at* http://www.kennedy-fire.com/PDFs/isfipaper.pdf.

[59] *See* DeHaan, *supra* note 52, at 220.

[60] *See* NFPA 921, *supra* note 3, at 6.3.7.

appear to have complex patterns, these are the result of complex structural arrangements rather than any unusual property of the fire.[61]

[16] Most fire patterns are the direct result of fire plumes.[62] When the 3D conical plume meets a 2D surface, it creates effects that are interpreted as patterns, appearing as a cross-section of the plume.[63] Fire patterns may be found on any surface exposed to the effects of the fire or its by-products.[64] "Fire patterns represent demarcation lines of fire effects upon materials created by the 3D (conical) shape of the fire plume being cut (truncated) by an intervening two-dimensional surface such as a ceiling or a wall."[65] In addition to structural surfaces, fire patterns are found on various interior surfaces like appliances, furniture, and other personal property items.[66]

[17] Currently, there is not much agreement on what quantitative interpretation, if any, can be placed on such patterns.[67] Because the interpretation of all possible fire patterns cannot be traced directly to scientific research,[68] a comprehensive fire investigation seeks alternative interpretations of a given pattern.[69] Nevertheless,

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[61] *See* DeHaan, *supra* note 52, at 222; *see also* ICOVE, *supra* note 28, at 43 (stating that "[s]uperposition is the combined effects of two or more fires or heat transfer effects, a phenomenon that may generate confusing fire damage indicators.").

[62] *See* NFPA 921, *supra* note 3, at 6.3.2.1.

[63] *See id.* at 6.3.2.1.

[64] *See id.* at 6.3.3.

[65] *See id.* at 3.3.60.

[66] *See id*. at 6.3.3.

[67] *See* VYTENIS BABRAUSKAS, WOOD CHAR DEPTH: INTERPRETATION IN FIRE INVESTIGATIONS (presented at the International Symposium on Fire Investigation, June 2004) *available at* http://www.doctorfire.com/WoodCharring.pdf.

[68] *See generally* Vincent Brannigan & Jose Torero, *The Expert's New Clothes: Arson Science After Kumho Tire* (July 1, 1999) *available at* http://firechief.com/mag/firefighting_experts_new_clothes/ (casting doubt on the science of fire patterns due to a "serious lack of high-level research.").

[69] *See* NFPA 921, *supra* note 3, at 6.3.7; *see also id.* at 17.4.1.3 (cautioning an investigator from assuming "that the fire at the origin burned the longest and therefore fire patterns showing the

inexpert fire investigators continue to apply assumptions that have never been subjected to rigorous or extensive validity testing while relying exclusively on fire pattern analysis for origin and cause determinations.[70] Clearly, "if patterns are to be used for origin and cause determination, forensic methods to identify the specific source of a pattern need to be developed and rigorously vetted."[71]

E. Fire Testing: Negligible Probative Value to Fire Investigations

[18] Traditional fire testing results are often incorrectly applied by fire investigators to assist in fire pattern analysis, even though most tests were not conducted or designed to support such undertakings.

> [F]ire test methods measure and describe the response of materials, products, and systems to sources of heat or flame under *controlled conditions* [and utilize] standards [that] cover the fire properties (including ignition, burning rate, flame spread, heat and smoke release) of a wide range of materials, including construction materials, furniture, electrical and optical fiber cables, apparel and textiles, plastics, petroleum products, paints, and much more.[72]

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greatest damage must be at the area of origin. Greater damage in one place than in another may be the result of differences in thermal exposure due to differences in fuel loading, the location of the fuel package in the compartment, increased ventilation, or fire-fighting tactics."), Ronald L. Hopkins, et al., *Fire Pattern Persistence and Predictability During Full Scale Compartment Fire Tests And The Use For Comparison of Post Fire Analysis* at 13 *available at* http://tracefireandsafety.com/FireInvestigationResearch/RonHopkinsFM-09.pdf (stating that "fire investigators should not rely on a single fire pattern to identify the origin of a fire. Large boundary fire patterns after transition to full room involvement, differences of fire patterns near or at ventilation openings, effects of large fuel packages within the compartment all require further analysis. It is here that subtle fire patterns lead an investigator to a more defined area of origin or even a point of origin."); *cf.* Vytenis Babrauskas, *Charring Rate of Wood as a Tool for Fire Investigations* 10 (May 2005) *available at* http://www.doctorfire.com/ WoodCharring.pdf (concluding that "[e]specially rapid charring rates in floor constructions imply high heat fluxes and good ventilation—they are not an indicator that liquid accelerants were used.").

[70] *See* Brannigan & Torero, *supra* note 85.

[71] *See* FIRE PROTECTION RESEARCH FOUNDATION, *supra* note 9, at 5.

[72] *See* ASTM FIRE STANDARDS AND RELATED TECHNICAL MATERIAL, Abstract, (7th ed. 1996) *available at* http://www.astm.org /BOOKSTORE/COMPS/189 htm (emphasis added).

Fire pattern damage phenomena resulting from fire testing include "demarcations, surface effects, penetrations, and loss of materials."[73] Investigators use fire testing to "confirm or reject hypotheses about the fire's ignition or spread, validate the predictions of computational models, or those of experienced investigators, or demonstrate the roles of various factors in the fire and its effects on occupants."[74]

[19] Fire testing approaches include various modeling methods, from bench-scale to full-scale.[75] In comparison to testing full-scale models, scaled-down replicas of rooms or furnishings provide useful information with a reduction in testing costs and complexity.[76] Because of the limited relationship between structural surfaces or conditions and ignition, scaled-down tests are particularly helpful in testing ignition and incipient fire hypotheses.[77] Although these tests have been developed by the American Society for Testing and Materials (ASTM) to assess the ignitability of materials and the nature and speed of flame

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[73] *See* ICOVE, *supra* note 28, at 105.

[74] *See id.* at 262; *see also* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 4-1, 4-2 ("In the laboratory, scientists can control and vary the conditions in order to isolate exclusive effects and thus better understand the factors that influence certain outcomes. . . . Those data—measurements collected through methodical prescribed observations under well-specified and controlled conditions—are then analyzed to support or refute the hypothesis.").

[75] *See* Yun Jiang, Decomposition, Ignition, and Flame Spread on Furnishing Materials 1 (2006) (unpublished Ph.D. dissertation, Victoria University, Australia) (on file with author) ("Bench scale testing devices, such as the cone calorimeter and the Lateral Ignition and Flame Transport (LIFT) . . . [m]iddle scale testing devices, like the single burning item and the furniture calorimeter . . .[and] [f]ull scale methods, such as the room/corner burning test and room calorimeter.").

[76] *See* ICOVE, *supra* note 28, at 271.

[77] *Id.*

propagation,[78] the geometry of a scaled-down model can often limit the application of testing results to the fire being investigated.[79]

[20] At the other end of the spectrum, the Standard Guide for Room Fire Experiments, ASTM E603-01, describes the criteria for full-scale testing.[80] This guide details the testing and evaluation of "the fire response of materials, assemblies, and room contents in real fire situations that cannot be determined in small-scale tests."[81] In reality, only a complete reconstruction of the fire can reveal the complex interactions between the fire and various fuels resulting in rapid transition to the flashover of an initial fire, but such a reconstruction can only be accomplished in a few select facilities with the necessary resources.[82] Unlike the controlled environment of scaled-down test, a full-scale replication of a room fire introduces "uncontrollable variables, mostly linked to ventilation."[83]

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[78] *See generally* ASTM FIRE STANDARDS 1449 (6th ed. 2004) (stating that none of the different tests for assessing the flammability of materials "attempts to relate its measured test results to theories of ignition, spread or combustion. Consequently, the test results are limited in their use, but often widely applied."), VYTENIS BABRAUSKAS, IGNITION HANDBOOK 499 (2003) (stating that "principles governing ignition sources are often poorly known . . . [d]espite its importance for understanding real fires, research in this area was nearly non-existent until the 1970s and is still scattered and incomplete.").

[79] *See* ICOVE, *supra* note 28, at 262.

[80] *Id.*

[81] *Id*. at 273. *See also id*. at 263 ("Most ASTM standard methods include an advisory comment regarding use of the method to compare materials or their performance under controlled conditions to assess the possible contributions a material might make in a real fire and not to use results to predict what a product *will* do when exposed to a real fire." Most test for flammability and ignition temperature, but also measured is char length, distance of char extension, rate and distance of flame movement [or spread], flame spread properties, percentage area destroyed by flame and the time required), measurement of gases present or generated during fires; *see, e.g.*, ASTM E1352, Standard Test Method for Cigarette Ignition Resistance of Mock-Up Upholstered Furniture Assemblies); *but see* ICOVE, *supra* note 28, at 113 ("Expert conclusions or opinions on the strength of these hypotheses rest partially on the use of accepted and historically proven fire testing techniques that validate this methodology and can be easily replicated.").

[82] ICOVE, *supra* note 28, at 285.

[83] *See* G. Gorbett, et al., *Fire Pattern Persistence Through Post-Flashover Compartment Fires*, 13 (2007) *available at* http://people.eku.edu/gorbettg/index_files/BodycoteFire-Fire%20Patterns%20Persistence%20Paper-Gorbett%20and%20Kennedy.pdf.

Because of these complications, full-scale tests are rarely reproducible.[84] Moreover, not only are full-scale tests dangerous, the quantitative measurements are limited by environmental constraints, expense, and technical challenges.[85]

[21] To overcome these challenges, computer fire modeling is also used for fire testing.[86] While computer fire models were first developed to study fire safety, they have been used in forensic fire investigation since the early 1990s.[87] But the application of experimental data directly to the modeling of ignition and flame spread in a real fire environment is seriously limited by complications of geometry and flow conditions.[88] The criteria currently used to determine the ignition of solid fuels are incapable or inaccurate for ignition prediction in complicated environments.[89] "Even for the computational fluid dynamics (CFD) model, which has the ability to describe the combustion process in detail, the flame spread modeling is still relatively crude."[90]

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[84] *Id.*

[85] BFRL Strategic Goal: Measurement Science for Innovative Fire Protection, Jan. 5, 2010, http://www.nist.gov/bfrl/innovative_fireprotection_goal.cfm; *cf.* Craig Beyler, et al., *Fire Resistance Testing for Performance-Based Fire Design of Buildings. Final Report*, 7 NIST GCR 07-910 (Jun. 2007) ("testing products at the upper bound of temperature level expected is currently the only way to demonstrate the overall performance of a material.").

[86] J.C. Martin Delemont, *Application of Computational Fluid Dynamics Modeling in the Process of Forensic Fire Investigation: Problems and Solutions*, FORENSIC SCIENCE INTL. 167 (2007) available at http://www.sciencedirect.com.

[87] *Id.*

[88] Jiang, *supra* note 75, at 204–05.

[89] *Id.* at i; *cf.* Leonard Y. Cooper & Jean-Marc Franssen, *A Basis For Using Fire Modeling With 1-D Thermal Analysis Of Barrier/Partitions To Simulate 2-D and 3-D Barrier/Partition Structural Performance In Real Fires*, NIST (Sept. 1998) ("because of intense computational requirements, the general use of a multi-dimensional (vs. a one-dimensional) barrier/partition thermal analysis in the fire modeling part of the problem is not now practical, and is not expected to be practical in the foreseeable future."); Kevin McGrattan, *Modeling Fire Growth and Spread in Houses*, Building and Fire Research Laboratory, National Institute of Standards and Technology ("Because of the cost of the three-dimensional, time-dependent calculation of the gas phase flow, the radiation and solid phase routines must be relatively simple and efficient.").

[90] *See* Jiang, *supra* note 75, at 61; *see also* Frederic B. Clarke III, et al., *Fire Risk Assessment Method: Final Report*, I-34 (National Fire Protection Research Foundation, July 1990)

[22] Part of the problem is the minimal data collected in a standardized fire test.[91] The data on the ignition and fire response of specific bands or designs of products are also limited.[92] And if reported to the Consumer Product Safety Commission, the data are not made available to the general public.[93] Moreover, standardized fire tests "may not reflect the full range of end-use configurations or applications."[94] The reproducibility of standard furnace tests illustrates this concern. "Fire resistance tests are unique within the fire test world in that the apparatus is only generally specified in the test standard. Fuels, burners, furnace linings, furnace dimensions, loading levels, and loading mechanisms are either unspecified or only generally specified."[95] This lack of specificity has made reproducing test results in another laboratory virtually impossible.[96]

[23] In 2003, the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) opened a new $135 million National Laboratory Center in suburban Maryland.[97]

("properties cannot be measured; they must be estimated."); *id*. at III-1 ("In an actual fire, there are so many more variables which bear on the outcome of a fire than can be known in advance . . . so the predicted outcome may not reflect the actual event."); *BFRL*, *supra* note 85 ("the complexity of the phenomena that control fire dynamics renders computer predictions approximate, at best.").

[91] Jesse Beitel, Nestor Iwankiw, *Analysis of Needs and Existing Capabilities for Full-Scale Fire Resistance* 47 NIST GCR 02-843-1 (Revision) (Oct. 2008).

[92] Fire Protection Research Foundation, *supra* note 9, at 6.

[93] *Id.*

[94] *Id.*

[95] Beyler, *supra* note 85, at 1.

[96] *Id.*, *see also* Thomas G. Cleary, James G. Quintiere, *A Framework for Utilizing Fire Property Tests*,1 NISTIR 4619 (Aug. 1991) ("each regulatory agency or government has laid out its own tests and procedures creating an array of different results . . . [fire] test methods stand more on their longevity, than on their scientific merits . . . The solution to this state of affairs is, however, not readily accessible since as technical consensus has not yet been developed from the science of fire.").

[97] STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 68.

This Center houses a unique fire testing facility designed to support fire investigations.[98]

> The Fire Research Laboratory will conduct forensic research, case support, training, and education for fire investigation and analysis for ATF-certified fire investigators, prosecutors, and the fire-investigation community. The Laboratory will provide forensic fire analysis to help investigators accurately recreate the fire scene and study various potential ignition scenarios to determine the origin and cause of fires. In addition, applied research will be conducted that could develop practical tools that fire investigators can use on the scene.[99]

[24] In sum, "experimental methods cannot be the exhaustive means of investigation of fire performance [because] . . . prediction of real fires must be validated by experimental results and on-sight fire surveys (after a fire incident has happened)."[100] Ultimately, standardized fire testing of common upholstered household products, designed to capture and preserve fire effects, will be undertaken and will most likely yield usable pertinent data for fire pattern analysis.[101]

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[98] *Id.* at 2–10.

[99] Michael L. Donahue, *The ATF Fire Research Laboratory: A New Forensic Resource for Fire-Scene Investigations*, FORENSIC SCIENCE COMMUNICATIONS, Vol. 4 No. 1 (Jan. 2002).

[100] Jiang, *supra* note 75, at 2.

[101] Björn Sundström, *A Methodology To Create a Design Fire*, NIST workshop at http://www.fire nist.gov/bfrlpubs/flamespread/Abstract/Sundstrom%20Abstract.pdf ("the method to arrive at a plausible design fire has been the objective for much research work over the years. However, methods that are envisaged internationally are still simple and rather crude and needs to be further improved to be more versatile.); ICOVE, *supra* note 28, at 269 ("The geometry of the test compartment is also important. The same piece of furniture may yield different heat outputs or fire patterns if tested in a corner or against a wall as opposed to its behavior if tested in the center of a large room that minimizes radiant feedback or ventilation effects"); T.J. Ohlemiller, *Flammability of Upholstered Furniture*, NISTIR 6030 THIRTEENTH MEETING OF THE UJNR PANEL ON FIRE RESEARCH AND SAFETY, Vol. 2, 216 (Building and Research Laboratory-NIST Mar. 1996) ("[T]he fire behavior of upholstered furniture items can be among the most non-ideal imaginable due to the strong role played by material movement in response to heat. Thermoplastic materials flow under the influence of gravity, moving fuel and heat to new, ill-defined locations."); Daniel Gross, *Data Sources for Parameters Used in Predictive Modeling of Fire Growth and Smoke Spread*, 2

F. Fire Pattern Studies: Hypotheses Validation or Merely Speculation?

[25] Tests and studies have recently been undertaken by private, governmental, and educational entities to broaden the understanding of fire pattern production and to quantify findings concerning the same.[102] "Given the limited number of experiments in the literature and the large number of variables it has been difficult to fully understand a cause and effect relationship between the fire scenarios and the resulting patterns."[103] Although future testing is likely to be informative, "questions regarding the repeatability of burn patterns or the capability to re-create burn patterns reliably has not been demonstrated."[104] These disparate

NBSIR 85-3223 (U.S. Department of Commerce, National Bureau of Standards, Sept. 1985) ("Organic materials . . . experience significant endothermic and exothermic reactions, phase changes, and physical changes (e.g. deformation, cracking, charring) which sometimes limits measurement of thermophysical properties beyond ordinary or moderately elevated temperatures."); Vytenis Babrauskas, *Bench-Scale Predictions of Mattress and Upholstered Chair Fires – Similarities and Differences*, 9 (National Institute of Standards and Technology, Building and Fire Research Laboratory, March 1993) ("Much of commercial furniture is, in fact, highly non-homogenous, and is likely to contain areas sensitive to ignition by a given source, versus those less so."); BABRAUSKAS, *supra* note 78, at 932 ("Radiant ignition [of upholstered items] can take place under piloted or unpiloted conditions, but few unpiloted tests have been run on furniture assemblies.").

[102] Madrzykowski, *supra* note 8, at 20 ("USFA burn pattern tests – [i]n conjunction with NIST, the USFA conducted a series of full-scale fire experiments to study the development of fire patterns . . . NIJ full-scale room burn pattern study – [u]nder the sponsorship of the National Institute of Justice (NIJ), the BFRL, and the Office of Law Enforcement Standards at NIST conducted a series of experiments with the University of Maryland, Maryland Fire & Rescue Institute."); *see also* G. Gorbett, *supra* note 83, at 2 ("[T]he Advanced Fire Pattern Research Project (AFPRP) was created to provide and report continuing research into the nature and dynamics of fire pattern production and analysis. Recognizing the need for an information data collection, preservation, and technology transfer system, the AFPRP was born.").

[103] D. Madrzykowski & K. McGrattan, *Analysis of Fire Plume/Wall Interactions and Burn Pattern Repeatability*, (Building Fire and Research Laboratory, National Institute of Standards and Technology, Sept. 2008) *available at* http://www.nist.gov/bfrl/fire_protection/fireservice/anal_fire_plumewall_interact_burn_pat_repeat.cfm.

[104] *Id*.

results have led some to conclude that fire patterns are not as reliable as once believed.[105]

[26] Researchers have yet to employ emerging 3D technology to recreate and examine fire patterns in testing forums.[106] In most instances, researchers utilize thermocouple trees and heat flux transducers to capture temperature data, perform heat and flame vector analysis and depth of calcination calculations to measure resulting burn patterns, and document findings using digital, 35mm video and still photography, direct observations, written notes, and diagrams.[107] But, while these are the standard techniques of fire pattern testing, studies have produced differing results concerning the reliability of fire pattern analysis and methodologies.

[27] In a full-scale room pattern study, Anthony D. Putorti, using the standard methodology to test the same method of ignition, identified significant differences in "the severity of burning, the locations of patterns, and the types of patterns present" of the experimental models and their furnishings.[108] Putorti concluded that there was a general lack of pattern consistency in the study.[109] Other researchers, despite an ability to produce reliable information concerning a fire's

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[105] Madrzykowski, *supra* note 8, at 21("Unfortunately for investigators, the replicate experiments also produced some significant differences in the severity of burning, locations of patterns and types of patterns present. For example, with the exception of the burn patterns on the wall above the upholstered chair, the walls yielded significantly different patterns.").

[106] *Cf.* Gorbett, et al., *Full-Scale Room Burn Pattern Study*, International Symposium on Fire Investigation Science and Technology 207–08, 210, 213–15 (2006) (indicating their study was conducted using standard techniques for burn pattern analysis, such as calcination measurements, flame vector analysis, and utilizing heat flux transducers and thermocouple trees to measure temperature); Ronald L. Hopkins et al., Fire Pattern Persistence and Predictability on Interior Finish and Construction Materials During Pre and Post Flashover Compartment Fires 5, *available at* http://www kennedy-fire.com/PDFs/FirePatternsPersistance.pdf (designing full-scale tests to study "standard fire pattern analysis methodologies, such as heat and flame vector analysis, depth of calcination measurement, depth of char, and truncated cone pattern analysis").

[107] Gorbett, *supra* note 106, at 207–08, 210, 213–15; Hopkins, *supra* note 106, at 5.

[108] ANTHONY D. PUTORTI, JR., U.S. DEPARTMENT OF JUSTICE, FULL SCALE ROOM BURN PATTERN STUDY NIJ REPORT 601-97, 26 (1997), *available at* http://tracefireandsafety.com/FireInvestigationResearch/FullScaleBurnTests-Putorti.pdf.

[109] *Id.*

point of origin, determined that they needed more conclusive findings and proposed new testing criteria that could yield more valuable data.[110]

[28] Similarly, James H. Shanley and Patrick M. Kennedy found the resulting patterns of their test plan "useful for determining the point of origin of [the test] fires."[111] Researchers conducting a different experiment determined that "the fire plume and the various fluxes generated by it are the primary means of pattern production in the early stages of a fire," and "that both movement patterns and intensity patterns, change continuously during the life of the fire, . . . evolv[ing] from distinct lines of demarcation to more subtle lines of demarcation."[112]

[29] Gorbett, Hicks, Kennedy, and Hopkins conducted a study that further verified "fire patterns existing pre-flashover conditions remain post-flashover."[113] In another experiment, the same researchers were able to demonstrate that the factors of the degree of ignitability of a surface, the amount of heat produced by combustion, and the mass consumed by the resulting fire could be used to consistently recreate fire patterns.[114] Furthermore, they found they could reliably determine "established pattern point, the point at which enough heat was imparted onto the surface by the flame plume to produce a visible pattern."[115] The

[110] Hopkins, *supra* note 106, at 16 ("Changes will include moving the origin, analysis of the persistence of patterns well after flashover, analyzing the patterns that remain after igniting a small fuel next to a large fuel and analyzing whether a reliable origin can be determined; the use of FDS/ Smokeview in analyzing fire patterns, and the addition of ignitable liquids to the ignition scenario.").

[111] James H. Shanley, Jr. & Patrick M. Kennedy, *Program for the Study of Fire Patterns*, *in* NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY ANNUAL CONFERENCE ON FIRE RESEARCH: BOOK OF ABSTRACTS 149, 150 (1996), *available at* http://fire nist.gov/ bfrlpubs/fire96/PDF/f96156.pdf.

[112] *See* G. Gorbett, *supra* note 83, at 2, 10, 15.

[113] Gorbett, *supra* note 106, at 217–18.

[114] William Hicks, et al., *Advanced Fire Pattern Research Project: Single Fuel Package Fire Pattern Study, International Symposium on Fire Investigation Science and Technology* 221, 228, 230 (2006) *available at* http://tracefireandsafety.com/FireInvestigationResearch/ SingleFuelPackage-Hicks06.pdf.

[115] *Id.* at 228.

reliability of pattern formation was verified by another study focusing on the development columnar, conical and triangular pattern formations.[116]

[30] Further efforts by Putorti provided "a means for fire investigators to predict the quantity of spilled gasoline necessary to produce a fire pattern of a particular size on various types of commonly used flooring materials."[117] Future controlled research of fire pattern analysis will likely provide significant imaging for database input for the purposes of 3D fire pattern comparisons.

G. Fire Pattern Analysis and Law: An Illusory Gatekeeper?

[31] Judges are tasked as gatekeepers to ensure reliability of the ever-increasing deluge of proffered scientific evidence that is inundating the legal arena. Courts routinely admit scientific evidence in spite of inadequate assurances of reliability, and instead tether admission of this evidence to the investigator's adherence to an established but nevertheless subjective investigative methodology.[118] Commentators acknowledge:

> [T]he existing legal regime—including the rules governing the admissibility of forensic evidence, the applicable standards governing appellate review of trial court decisions, the limitations of the adversary process, and judges and lawyers who often lack the scientific expertise necessary to comprehend and evaluate

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[116] William Hicks, et al., *Advanced Fire Pattern Research Project*, *International Symposium on Fire Investigation Science and Technology* (2006), at 1, 10 *available at* http://people.eku.edu/gorbettg/index_files/ADVANCEDFIREPATTERN-PMKChanges10-12-06.pdf.

[117] ANTHONY D. PUTORTI, JR., U.S. DEPARTMENT OF JUSTICE, FLAMMABLE AND COMBUSTIBLE LIQUID SPILL/BURN PATTERNS NIJ REPORT 604-00, 12 (2001), *available at* http://fire nist.gov/ bfrlpubs/fire01/PDF/f01023.pdf. ("[This study] also includes measurements of spill fire heat release rates that provide fire investigators and other fire professionals with previously unavailable data for fire modeling and fire scenario evaluation.").

[118] *See* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 1–14 ("In a number of forensic science disciplines, forensic science professionals have yet to establish either the validity of their approach or the accuracy of their conclusions, and the courts have been utterly ineffective in addressing this problem.").

> forensic evidence—is inadequate to the task of curing the documented ills of the forensic science disciplines.[119]

[32] In *Daubert v. Merrell Dow Pharmaceuticals, Inc.*,[120] the Supreme Court held that "under the [Federal Rules of Evidence] a trial judge must ensure that any and all scientific testimony or evidence admitted is not only relevant, but reliable."[121] The Court emphasized that the focus of an expert's testimony should be scientific, to ensure that "evidentiary reliability will be based upon scientific validity."[122] Rather than an expert's conclusions, the Court instructed trial courts to focus on the expert's principles and methodologies.[123]

[33] In accordance with its holding in *Daubert*, the Court subsequently provided several factors to help trial courts assess the reliability of an expert's technique:

> 1) whether a method consists of a testable hypothesis; 2) whether the method has been subject to peer review; 3) the known or potential rate of error; 4) the existence and maintenance of standards controlling the technique's operation; 5) whether the method is generally accepted; 6) the relationship of the technique to methods which have been established to be reliable; 7) the qualifications of the expert witness testifying based on the

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[119] *Id.* at 2–23.

[120] 509 U.S. 579 (1993)

[121] *Id.* at 589; *see also* FED. R. EVID. 702 ("If scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise, if (1) the testimony is based upon sufficient facts or data, (2) the testimony is the product of reliable principles and methods, and (3) the witness has applied the principles and methods reliably to the facts of the case.").

[122] *Daubert*, 509 U.S. at 590 n.9.

[123] *Id.* at 595.

methodology; and 8) the non-judicial uses to which the method has been put.[124]

[34] In practice, however, courts have failed to properly apply this regime to forensic evidence in general, and to fire pattern analysis in particular.[125] "[W]hen faced with forensic methodologies, trial courts rely in part upon legal memoranda, scientific documents, and precedent—rather than factual hearings with live witnesses to determine their admissibility."[126] When challenges to scientific evidence are forwarded, "courts treat such attacks in a fact-like manner; the fact-finder considers them through a case-specific lens as relevant only to the weight of the evidence."[127] Due to this legally qualified reception, many forensic science disciplines, including fire pattern analysis, have attained the lofty status of unimpeachable scientific law.[128] A laundry list of possible erroneous court decisions involving dubious fire pattern analysis has surfaced and lodged fire investigation methodologies, as well as practitioner qualifications, into a quagmire of controversy.[129]

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[124] Hoang v. Funai Corp. Inc., 652 F. Supp. 2d 564, 566–67 (M.D. Pa. 2009) (citing Calhoun v. Yamaha Motor Corp., 350 F.3d 316, 321 (3d Cir. 2003) (citing *In re* Paoli R.R. Yard PCB Litigation, 35 F.3d 717, 742 n.8 (3d Cir. 1994).

[125] *See* ICOVE, *supra* note 28, at 285.

[126] Erin Murphy, *The New Forensics: Criminal Justice, False Certainty, and the Second Generation of Scientific Evidence*, 95 CAL. L. REV. 721, 757–58 (2007); *see also* William A. Tobin & William C. Thompson, *Evaluating and Challenging Forensic Identification Evidence*, CHAMPION MAGAZINE, Jul. 2006, at 17, *available at* http://www nacdl.org/public.nsf/698c98dd101a846085256eb400500c01/8a20d040b54b23c9852571c500787130?OpenDocument&Highlight=0,forensic,forensics,evidence ("History has shown that assertions of expertise, unsupported by scientific research, are often wrong.").

[127] Murphy, *supra* note 126, at 759.

[128] *See id.* at 758–59; *see also* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 1–14.

[129] *See generally* ICOVE, *supra* note 28, at 328–37 (discussing arson cases where expert's flawed testimony led to conviction, including People v. Hobley, 637 N.E.2d 992 (Ill. 1994) (defendant convicted on erroneous evidence where investigator's opinion failed to account for the lack of an accelerant in the burn patterns); Willis v. State, 785 S.W.2d 378 (Tex. Crim. App. 1989) (expert's testimony as to the use of an accelerant was deemed unconscionable where lab analysis revealed no traces of accelerant on defendant's clothing); Cacy v. State, 901 S.W.2d 691 (Tex. Crim. App.

[35] In addition to meeting the "exacting standards" of *Daubert*,[130] there are two important considerations relating to the admission and reliability of fire-related forensic evidence that courts should consider.[131] First, "the extent to which a particular forensic discipline is founded on a reliable scientific methodology that gives it the capacity to accurately analyze evidence and report findings."[132] Second, "the extent to which practitioners in a particular forensic discipline rely on human interpretation that could be tainted by error, the threat of bias, or the absence of sound operational procedures and robust performance standards."[133]

H. Fire Scene Photography: Inadequate Data Capture

[36] Maximum evidentiary value is preserved from a fire scene through a comprehensive strategy that calls for systematic documentation of the investigation, to support and verify investigative opinions and conclusions.[134] Photographic documentation in fire investigations is likewise significant since arson investigators often rely on photographs to form an opinion about the cause of the fire.[135] They are used as the basis for testimony reasonably relied on by experts in the field and are thus an appropriate basis for an expert opinion.[136] Photographic images often constitute the primary evidence gleaned from a fire scene.[137] For this reason, fire scenes should be photographed carefully to record

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1995) (false lab analysis and challenge to expert's flawed theory led to unprecedented parole approval)).

[130] Weisgram v. Marley Co., 528 U.S. 440, 442 (2000).

[131] STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 3–2.

[132] *Id.*

[133] *Id.*

[134] *See* NFPA 921, *supra* note 3, at 15.1.2.

[135] *See* U.S. v. Gardner, 211 F.3d 1049, 1054 (7th Cir. 2000).

[136] *See id.*

[137] *See generally* Technical Working Group on Fire/Arson Scene Investigation, *Arson Scene Evidence: A Guide for Public Safety Personnel* (U.S. Dept. of Justice 2000) *available at* http://www.ncjrs.gov/pdffiles1/nij/181584.pdf.

general features and their relationships with other objects nearby.[138] Photographs can be helpful in determining how the fire spread from possible ignition sources to other combustible objects or to adjacent structures.[139] But evidence consisting of only a few photographs and a scene diagram are often not sufficient to capture vital information on fire dynamics and building construction.[140]

[37] Forensic photographers are tasked with producing images that not only depict reality, but also provide "sufficient information to permit complete and accurate analyses."[141] There are two broad categories for forensic photographs.[142] Documentary photographs mimic rough sketches, "drawn to no particular proportion or scale."[143] Metric photographs are more analogous to engineering drawings or maps, and hold "the information necessary for deriving quantitative data."[144]

[38] Fire investigators use both traditional photographic methods and digital technologies.[145] The two technologies are fundamentally different in that "a digital camera uses a light sensitive silicon chip as the focal plane instead of film."[146] The quality of the initial images produced by film cameras and digital cameras differentiates the two technologies, with the quality of images produced

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[138] *See id.* at 29.

[139] *See, e.g.*, *id*.

[140] *See, e.g.*, N.J. Manf. Ins. Co. v. Hearth & Home Tech. Inc., No. 3:06-CV-2234, 2008 WL 2571227, at *11 (M.D. Pa.) ("The photographs provided to date do not present sufficient documentation of the fireplace bump-out or associated wall structure above the fireplace to allow for a complete evaluation of the burn patterns or how they were caused.").

[141] *See* William G. Hyzer, *Forensic Photogrammetry*, in FORENSIC ENGINEERING 357 (Kenneth L. Carper, ed., 2001).

[142] *Id.* at 328.

[143] *Id*.

[144] *Id.*

[145] *See* James Campbell, *Evidentiary Requirements for the Admission of Enhanced Digital Photographs*, 74 DEF. COUNS. J. 12, 12 (2007).

[146] *See id.* at 13.

on 35mm film being superior.[147] "Typically, 35mm film yields better resolution, a higher dynamic range, and better color range and fidelity than digital images. In contrast, digital images tend to have lower resolution, and therefore poor image quality in the brightest portions of the scene being recorded."[148]

[39] The interplay of many variables can result in distortion of the subject in the photograph.[149] In particular, alteration of the lens type and camera position introduces the greatest distortion.[150] But even the slightest changes in scene lighting can produce significant differences in some photographs.[151] Accordingly, courts should take these variations into account, recognizing effects of lighting on the apparent dimensions or depth of a photograph's subject.[152]

[40] The photographic documenting of a fire scene is only complicated by the reflective light properties of charring.[153] Typically, there is insufficient light to focus a camera accurately,[154] and flash lamps are often ineffective because of the

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[147] Jill Witkowski, *Can Juries Really Believe What They See? New Foundational Requirements for the Authentication of Digital Images*, 10 WASH. U. J.L. & POL'Y 267, 269 (2002).

[148] *Id.*

[149] Benjamin V. Madison III, Note, *Seeing Can Be Deceiving: Photographic Evidence in a Visual Age – How Much Weight Does It Deserve?* 25 WM & MARY L. REV. 705, 716 (1984) ("Lens type, camera position or perspective, lighting, film type and speed, lens filters, camera quality, length of exposure, and the development process can create distortion."); *see also* David Beckman & David Hirsch, *Developing Evidence: Imaging Software Can Help your Pictures Tell the Story*, 62 A.B.A. J. (Aug. 2003) (noting that lighting, position of the camera relative to the subject, type of film, lens and any number of camera settings can affect the truth shown by any photograph).

[150] *See* Madison, *supra* note 149, at 716.

[151] *Id*. at 719–20 (Insufficient lighting minimizes the dimension of an object or the depth of a hole, for example, whereas enhanced lighting emphasizes both dimension and depth.").

[152] *Id*.

[153] *See* DeHaan, *supra* note 52, at 296; *see also* NFPA 921, *supra* note 3, at 15.2.3.1.1 ("The average fire scene consists of blackened subjects and blackened background, creating much less than ideal conditions for taking a photograph.").

[154] *See generally* Forensic Engineering and Fire Investigation, http://www.geers.com/blogs/labels/California.html (October 4, 2007, 20:15 EST and October 20, 2007, 11:35 EST) ("Dark deep spaces look like caves in the images . . . When working burned out rooms and building with practically no light, your camera may create out of focus images").

distance at which they are placed from the scene.[155] The minimal reflectivity of a burned scene,[156] and the high reflectivity of the burned wood can cause glare spots, making it all the more difficult to accurately photograph.[157] Although trained fire investigators may easily identify burn patterns in fire scene photographs, "the typical juror will have a hard time recognizing a burn pattern in a photograph . . . unless the photograph is enlarged so that it clearly shows the burn pattern or whatever else may be important in that picture."[158]

[41] Part of the problem is that photography is a 2D system.[159] With regards to determining the cause and origin of the fire, 2D photographs cannot possibly provide the same degree of information that examining the 3D objects can provide.[160] Furthermore, 2D data capture for fire scene documentation is presently mediocre due to distortion and poor image quality.[161] Two-dimensional data capture is also hampered by, among other things, "the light incidence angle, the camera view angle, variations on the reflectivity of the [target] surface, [and] light intensity."[162] Moreover, the phenomenon of "shadowing" plagues current fire-

155 *See* DeHaan, *supra* note 52, at 296.

156 Tony Cafe, *Photographing the Fire Scene* (Mar. 1994) *available at* http://www.tcforensic.com.au/docs/article1.html ("Photographs of the interior of a building are generally more difficult for the viewer to interpret that the exterior photographs as the interior surfaces are usually burnt and covered with a layer of soot, and the viewer is generally unfamiliar with such an environment."). *See generally* J. L. Harris, Sr., and, J. L. Harris, II, *Forensic Photography and Nighttime Visibility Issues*, 1085 J. FORENSIC SCIENCES, Vol. 37, No. 4 (Jul. 1992).

157 *See* DeHaan, *supra* note 52, at 296.

158 *See* Guy E. Burnette Jr., *Documentation of the Fire Scene: A Legal Perspective*, http://www.interfire.org/res_file/docscleg.asp (last visited April 6, 2010).

159 *See* Hyzer, *supra* note 141, at 356.

160 *See N.J. Manf. Ins. Co.*, 2008 WL 2571227 at *12.

161 *See* Scientific Working Group Imaging Technology (SWGIT), *Overview of SWGIT and the Use of Imaging Technology in the Criminal Justice System*, June 5, 2007, http://www.theiai.org/guidelines/swgit/guidelines/section_2_v2-0.pdf ("Capture is the process of recording data such as an image or video sequence").

162 Benjamin Bachrach, *Development of a 3D-Based Automated Firearms Evidence Comparison System*, 47 J. FORENSIC SCI. 1253, 1255 (Nov. 2002).

related photography and erodes its future usability for image analysis and comparison purposes.[163]

II. Emerging Forensic Imaging Technologies

A. Three-Dimensional Technology

[42] A picture may be worth a thousand words, but few investigators may realize that "a picture may also contain a thousand measurements."[164] Sizeable advances in the last three years have been made in the ability to visualize and extract image detail in three-dimensions.[165] The development of 3D crime scene impression technology has moved crime scene documentation beyond a "mere patchwork of pictures."[166] The use of 3D imaging for visualizing crime scenes "has lead to a change in the way information is disseminated in . . . investigation[s]."[167] "Three-dimensional imaging methods have been studied in order to determine if imaging methods can help to improve more traditional investigative work by providing virtual microscopes and surface comparison tools."[168] In the fields of photogrammetry and computer vision, many techniques

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[163] *Id*. ("[T]here may be regions of the surface where the captured data does not accurately reflect the surface features. Furthermore, . . . the angle of incidence of the light source can have a critical effect on the captured data, because arbitrarily small changes in the angle of incidence may determine whether [a surface feature] is detected or not (the same problem applies to the angle of view of the camera).").

[164] John H. Garstang, *Aircraft Explosive Sabotage Investigation*, in FORENSIC INVESTIGATION OF EXPLOSIONS 133, 153 (Alexander Beveridge ed., 1998).

[165] Simon Bramble, et al., *Forensic Image Analysis*, Address at the 13th INTERPOL Forensic Science Symposium (Oct. 2001), http://www.interpol.int/public/Forensic/IFSS/meeting13/Reviews/Image.pdf.

[166] G. Sasse, et al., *Digital Crime Scene Documentation, Reconstruction and Analysis; An Experience Report After Interdisciplinary Discussion Using the 3D Crime Scene Model*, Address at the Meeting of the International Association of Forensic Science (Aug. 2005), http://www.dcsr.ch/images1/downloads/IAFS_Poster_1k.pdf.

[167] *Id*.; *see also* Bachrach, *supra* note 162, at 1254–55 ("The main difference between 3D data capture and 2D data capture lies in the fact that 2D data capture is fundamentally an indirect measurement . . . while 3D data capture is for all practical purposes a direct measurement.").

[168] Sébastien Charles, et al., *Firearms—A Review: 2004 to 2007*, *in* 15TH INTERNATIONAL FORENSIC SCIENCE SYMPOSIUM INTERPOL—REVIEW PAPERS 25, 36 (Niamh Daéid ed., Oct. 2007);

have been developed that allow 3D structures to be constructed from photographs and video sequences.[169]

[43] "The three-dimensional reconstruction of a scene usually requires a matched pair of images recorded from two [or more] different vantage points . . . [but also] can be made from two or more photographic images of the scene exposed either simultaneously or sequentially."[170] The idea is to capture all three dimensions of an object.[171] Accurate fire scene reconstruction requires a quantitative analysis of the fire patterns, aimed at determining the location, profile, and the size of each.[172] Three-dimensional technology allows for imaging to be used for both pattern visualization as well as pattern measurement.[173] "[M]easurement helps reasoning with sizes and supports shape comparison providing partial compensation to the pitfalls of visual perception, adding quantitative content to an otherwise predominantly qualitative and subjective process."[174] Three-dimensional images provide both more accurate imaging of the

[169] *See* Bob Galvin, *Focus on Photography*, EVIDENCE TECH. MAGAZINE, Sept.–Oct. 2004, http://www.iwitnessphoto.com/iwitness/iwitness_in_%20evid_ tech_% 20magazine.pdf ("Photogrammetry is the science or art of analyzing images for the purpose of obtaining good, reliable measurements).

[170] *See* Hyzer, *supra* note 141, at 331 ("Stereophotography: A three-dimensional imaging process using a pair of spatially separated photographs to simulate binocular vision when viewed through a stereoscope or by stereo projection . . . to provide a three-dimensional representation of an object or scene.").

[171] *See* Charles Q. Little, et al., *Forensic 3D Scene Reconstruction*, Dept. of Energy's (DOE) Information Bridge: DOE Scientific and Technical Information (1999) at 2, http://www.osti.gov/bridge/servlets/purl/13967-Gey0Ey/webviewable/13967.pdf ("In a [3D] sense this means getting the front, back, and sides of everything.")

[172] *See* U.S. DEPT. OF JUSTICE OFFICE OF JUSTICE PROGRAMS, NATIONAL INSTITUTE OF JUSTICE, *Forensic Sciences: Review of Status and Needs*, 40 NCJ 173412 (Feb. 1999) ("However, this need is magnified for these [postblast and fire] scenes because three-dimensional mapping of the position of recovered traces of explosives or ignitable liquid residues can be used to estimate the size and operation of explosive and combustible devices or materials. Therefore, enhanced capabilities not only provide greater accuracy in recording the position of the evidence, but may actually materially contribute to the interpretation of the size and composition of devices and explosive or ignitable liquids used in the generation of observed effects.").

[173] Nicola Senin, et al., *Three-Dimensional Surface Topography Acquisition and Analysis for Firearm Identification*, 51 J. FORENSIC SCI. 282, 286–87 (Mar. 2006).

[174] *Id*. at 290.

depth and volume measurements,[175] and permit comparison of even microscopic data to solve crimes.[176]

B. Digital Imaging

[44] Digital imaging collects, generates, and preserves image data in a binary format, typically as videos or photographs.[177] Digital enhancement, meanwhile, creates a new image which is identical to the original, except for its altered characteristics.[178] "An image derived from the source image would be a first-order enhancement, an image derived from that image would be a second-order enhancement, and so on."[179] For many forensic applications, including fire investigations, capturing, displaying, and preserving images "is of equal or greater importance than actually viewing the specimen through a microscope."[180] Nevertheless, digital image processing is becoming more about image interpretation and analysis.[181]

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[175] Ilya Petrou, *3-D Technology: State-of-the-Art Imaging System Increases Photographic Accuracy*, DERMATOLOGY TIMES, Nov. 2008, http://www modernmedicine.com/modernmedicine/ article/ articleDetail.jsp?id=562922.

[176] Bachrach, *supra* note 162, at 1264.

[177] Catherine Guthrie & Brittan Mitchell, *The Swinton Six: The Impact of State v. Swinton on the Authentication of Digital Images*, 36 STETSON L. REV. 661, 662 (2007), *see also* U.S. DEPT. OF JUSTICE OFFICE OF JUSTICE PROGRAMS, NATIONAL INSTITUTE OF JUSTICE, *Forensic Sciences: Review of Status and Needs*, 40 NCJ 173412, at 66 (Feb. 1999) ("Digital Imaging: A process through which a picture is converted into a series of square electronic dots known as pixels. Manipulation of the picture is accomplished through computer software that changes the numerical value of each pixel.").

[178]Michael Cherry, *Reasons To Challenge Digital Evidence and Electronic Photography*, CHAMPION, Jul. 2003, at 42, 43 n. 1.

[179] *Id*. at 42.

[180] Meiji Techno Co., Ltd., *Choosing the Correct Microscope*, http://www meijitechno.com/ choosing.htm.

[181] *See* Jurrien Bijhold, et al., *Forensic Imaging: A Review: 2001 to* 2004, *in* 14TH INTERNATIONAL FORENSIC SCIENCE SYMPOSIUM INTERPOL—REVIEW PAPERS 189, 191 (Niamh Daéid ed., Oct. 2007).

[45] The quality of images used in forensic science is especially important to interpretation.[182] "Forensic image analysis involves the application of image science and domain expertise to interpret the content of an image and/or the image itself in legal matters."[183] In most forensic applications, interpretation and analysis often depend on properly "extracting a few numerical values, such as the number, size, shape or location of objects from the image."[184] "Statistical interpretation of the data allows comparisons of different populations, understanding of distribution plots, and other inferences about the original objects."[185] Thus, the focus is on both "recording an artifact's surface geometry and its photometric properties."[186]

[46] In the future, fire investigation will entail the use of modern imaging methods to deduce visual and numerical information from images, compare and differentiate their features, and interpret image configuration. These actions will, in turn, allow the prudent investigator to test proposed hypotheses against known circumstances, and answer reconstructive questions about the dynamic development of fire patterns to calculate the possibility that they are linkable to assumed fuel packages.

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[182] *See* Michael Heizmann, *Imaging and Analysis of Forensic Striation Marks*, OPTICAL ENGINEERING, Dec. 2003, at 3423, 3425.

[183] Scientific Working Group Imaging Technology (SWGIT), § 12, *Best Practices for Forensic Image Analysis*, at 1, http://www.theiai.org/guidelines/swgit/ [hereinafter SWGIT Best Practices].

[184] John C. Russ, *7th Annual Short Course and Workshop on Computer-Assisted Image Analysis and Measurement* (Jun. 2009), http://www.emc.missouri.edu/russcourse/Russ%20workshop %20description202009.pdf, *see also* Scientific Working Group Imaging Technology (SWGIT), § 1, *Overview of SWGIT and the Use of Imaging Technology in the Criminal Justice System*, at 3–4, http://www.theiai.org/guidelines/swgit/ ("Image analysis . . . involves the application of image science and domain expertise to examine and interpret the content of an image and/or the image itself in legal matters.").

[185] Russ, *supra* note 184; *see also* SWGIT Best Practices at 1, 3 ("Interpretation, as used here, is the application of specific subject matter expertise to draw conclusions about subjects or objects depicted in images. . . . Photographic comparison is an assessment of the correspondence between features in images and known objects for the purpose of rendering an expert opinion regarding identification or elimination.").

[186] Paul Debevec, *Image-Based Techniques for Digitizing Environments and Artifacts*, Fourth International Conference on 3-D Digital Imaging and Modeling (2003), http://www2.computer.org/portal/web/csdl/doi/10.1109/IM.2003.1240255.

C. Cameras

[47] New trends in digital imaging technology are suggesting a "revolution in 3D shape technology," fueled by lower cost digital cameras with sufficient resolution to create high quality 3D images.[187] This technology makes it possible to "bypass geometry acquisition, and directly create stylized renderings from images."[188] More advanced systems include software that permits image data to be exported to other rendering programs, which is used to create high-resolution, 3D digital recreations of a crime scene.[189]

[48] Proponents of these technologies call attention to the shortcomings of other scene acquisition systems.[190] For example, "[l]aser-based data collectors, such as Total Station, sell for thousands of dollars, while laser 3D scanners/cameras that produce virtual scene replicas sell for hundreds of thousands of dollars."[191] Moreover, laser-based technology sometimes requires an additional investment in software to upload the data collected at the scene for

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[187] Jiajun Zhu, et al, *Fast Omni-Directional 3D Scene Acquisition with an Array of Stereo Cameras*, http://www.cs.virginia.edu/~jz8p/pubs/3DIM07.pdf.

[188] Ramesh Raskar, et al, *Non-Photorealistic Camera: Depth Edge Detection and Stylized Rendering using Multi-Flash Imaging*, http://delivery.acm.org/10.1145/1020000/1015779/p679-raskar.pdf?key1=1015779&key2=8628220721&coll=GUIDE&dl=GUIDE&CFID=82655179&CFTOKEN=12022586.

[189] Bob Galvin, *Mapping Choices Abound as Traffic and Crashes Mount*, L. ENFORCEMENT TECH., Aug. 15, 2007, *available at* http://officer.com/print/Law-Enforcement-Technology/Mapping-choices-abound-as-traffic-and-crashes-mount/1$37948.

[190] *See generally* Voicu Popescu, et al., *The ModelCamera: A Hand-Held Device for Interactive Modeling*, 68 GRAPHIC MODELS 5, Sept. 2006, *available at* http://www.cs.purdue.edu/cgvlab/papers/popescu/popescuModelCamera3DIM2003.pdf (describing the difficulties of modeling with a laser range finder as opposed to the ModelCamera); Jarek Gryz1,et al., *3D Crime Scene Acquisition, Representation and Analysis*, at 10, http://vgrserver.cs.yorku.ca/~jenkin/papers/2008/csibook.pdf (describing the difficulty of constructing a crime scene model with underperforming equipment).

[191] ROSS M. GARDNER & TOM BEVEL, PRACTICAL CRIME SCENE ANALYSIS AND RECONSTRUCTION 256 (2009).

analysis.[192] While it is true that 3D cameras have limitations relating to image acquisition, the main disadvantages are their large size and prohibitive cost.[193]

D. Scanning Technologies

[49] The common 3D scanning methods are: "the object rotation method, the camera/imaging system transport technique, and the fixed imaging system with multiple cameras approach."[194] Although there are various techniques to capture static 3D images from a singular viewpoint,[195] newer scanning technologies combine the advantages of laser technology and digital imaging to increase data capture and ease of use.[196] The increase in data generate higher resolution 3D images, which virtually recreates the scene from multiple viewpoints.[197]

[50] Laser scanning technology uses laser triangulation and sensors to determine the light intensity and height and width profiles.[198] The method of projecting a laser onto the surface of an object and collecting the reflected data is known as the "sheet-of-light" technique.[199] These planar images are combined using computer hardware and software to generate a 3D image, layer by layer.[200] To enhance these 3D virtual images, some scanners use digital photography to

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[192] *See* Iris Dalley, *Developing and Using Demonstrative Exhibits in Support of the Crime Scene Analysis* in PRACTICAL CRIME SCENE ANALYSIS AND RECONSTRUCTION 256 (2009) ("The pulse laser technology requires software to retrieve and analyze the data collected.").

[193] Popescu, *supra* note 190, at 1.

[194] *Id.* at 12.

[195] Frank Chen, et al., *Overview of Three-Dimensional Shape Measurement Using Optical Methods*, 39 OPTICAL ENGINEERING 10, Jan. 2000, at 10, *available at* http://mesh.brown.edu/3DPGP-2007/pdfs/Chen2000.pdf.

[196] *See* Dalley, *supra* note 192, at 256.

[197] *Id.*

[198] MoviMED, MoviSCAN 3D, www.movimed.com/moviSCAN_3D_Cameras.htm (last visited Jun. 30, 2010).

[199] *Id.*

[200] *Id.*

capture and incorporate real-world images.[201] This can be accomplished by using a computer graphics technique called a "texture map," which makes the 3D images look more realistic.[202] This technique works by "mapping" triangular portions of a digital image onto a "3D triangular mesh" of the scan results.[203]

[51] Newer scanning technology includes hand-held devices that use geometric fusion algorithms to generate full surface shape measurements.[204] These "so-called third generation scanners" can generate complete scans without having to move the object being scanned or taking measurements from multiple locations.[205]

[52] Two other developments in forensic scanning technology are forensic 3D/CAD supported photogrammetry (FPHG)[206] and the combination of radiological digital imaging methods with photogrammetry and 3D surface scanning techniques.[207] FPHG is particularly helpful in 3D forensic documentation.[208] FPHG systems measure and calculate spatial locations of distinctive points on an object's surface and convert the data into a virtual 3D

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[201] Doug Schiff, *Who Says You Can't Do That? Crime Scene 3D Viewpoints Illustrating What Was Seen at the Scene*, FORENSIC MAGAZINE, Jun./Jul. 2007, *available at* http://www.forensicmag.com/articles.asp?pid=154.

[202] *Id.*

[203] *Id*.

[204] Adrian Hilton & John Illingworth, *Geometric Fusion for a Hand-Held 3D sensor*, 12 MACHINE VISION AND APPLICATIONS 44 (2000), *available at* http://www.ee.surrey.ac.uk/CVSSP/VMRG/Publications/hilton00mva.pdf.

[205] Eros Agosto, et al., *Crime Scene Reconstruction Using a Fully Geomatic Approach*, 8 SENSORS 6280, 6283–84 (2008), *available at* http://www mdpi.com/1424-8220/8/10/6280.

[206] M.J. Thali, et al., *Bite Mark Documentation and Analysis: The Forensic 3D/CAD Supported Photogrammetry Approach*,135 FORENSIC SCI. INT'L 115, 116 (2003).

[207] Anders Persson, Virtual Autopsy, 1, *available at* http://www.star-program.com/resource.ashx/abstract/977.

[208] *See generally* M.J. Thali, et al., *supra* note 206, at 120 ("The success of an FPHG (forensic 3D photogrammetry) evaluation of a forensically relevant object . . . depends primarily on the proficiency of the preparation and subsequent photographic recording of these objects.").

model.[209] According to one forensic expert, the combination of radiological digital imaging techniques of multislice computed tomography and magnetic resonance imaging, together with photogrammetry and 3D surface scanning, has "the potential to be one of the main diagnostic tools in forensic pathology in the future."[210] This high resolution shape and surface acquisition technique permits more accurate image capture of even the smallest artifacts; hence, a more detailed model is obtained.[211] These developments in forensic pathology have not only promoted virtual autopsies, but can also be translated into fire pattern analysis.[212] The implementation of these tools in a fire investigative capacity is not far off.[213]

[53] To achieve unadulterated data capture, many artifacts must "be brought into object scanning facilities to be photographed from many angles and illuminated under controlled forms of illumination."[214] Doing this requires the artifacts to be removed from the crime scene, where it may not generate any new interest by the investigator. Three-dimensional scanning technology, however, permits every object in the crime scene to be documented where it naturally rests, whether or not its significance in that place is initially recognized, and to be reviewed with ever more powerful software.[215]

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209 *See id.* at 116.

210 Persson, *supra* note 207, at 1.

211 *See id.* at 4.

212 *See id.*

213 ICOVE, *supra* note 28, at 340 ("MRI and CT Imaging . . . Such techniques have also been suggested for use in examination of melted or charred artifacts from fire scenes where nondestructive testing for pockets of liquid or similar nonradiopaque inclusions would be desirable. While expensive, such techniques may provide answers where X rays cannot"); id. (Polynomial Texture Mapping . . . A new method for increasing the photorealism of maps and complex surfaces is known as PTM. This technique could be used to enhance and visualize fire patterns on various surfaces").

214 Debevec, *supra* note 186.

215 Sasse, *supra* note 166.

E. Databases

[54] After forensic evidence from a crime scene has been collected and digitally recorded, the image data can be compared against a number of different databases.[216] It is anticipated that using 3D scans instead of digital images, which are recorded without standardized procedures, will improve these systems.[217] Adapting these 3D database comparison technologies for the purpose of fire pattern analysis is readily apparent.[218] Image comparison of fire patterns of known origin will remove interpretative endeavors from the chaotic world of subjectivity that it presently inhabits.

[55] Pattern recognition requires the statistical comparison of pattern data against known patterns or information extracted from such patterns.[219] The patterns to be classified are usually "sets of measurements or observations that present essential features in an appropriate multidimensional space."[220] Pattern recognition relies on an extensive presentation of basic methods in computer

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[216] Bijhold, *supra* note 181, at 196; *see generally* Gerhard Schreck, *Computerised Comparison of Toolmarks By the Pamir System*, INFO. BULL. SHOEPRINT/TOOLMARK EXAMINERS, Jun. 2001, at 23 ("…digital representation of samples are stored in a data base system, which enables a flexible management of . . . comparison procedures.").

[217] *See* Bijhold, *supra* note 181, at 196.

[218] *See generally* C. Wu, et al., *Two-Level Method For 3D Non-Rigid Registration With an Application to Statistical Atlases Construction*, *available at* http://www .andrew.cmu.edu/user/chenyuwu/visapp07.pdf ("…a two-level method for 3D non-rigid registration and apply the method to the problem of building statistical atlases of 3D anatomical structures.").

[219] Stefania Bandini, et al., *Emergent Spatial Patterns in Vegetable Population Dynamics: Towards Pattern Detection and Interpretation*, 2006 INT'L CONF. ON COMPUTATIONAL SCI. 294–295, *available at* http://www.springerlink.com/ content/107640k12325g286/fulltext.pdf.

[220] Alireza Akhbardeh, Signal Classification Using Novel Pattern Recognition Methods and Wavelet Transforms 29 (Mar. 9, 2007) (unpublished D.Tech. thesis, Tampere University of Technology) *available at* http://dspace.cc.tut fi/dpub/bitstream/handle/123456789/156/ akhbardeh.pdf?sequence=1.

vision including texture analysis and models, color, geometrical tools, and image sequence analysis.[221]

[56] Retrieval of pertinent fire pattern data can take many paths. Classification or description schemes utilize a statistical or syntactic approach and rely on content-based features extracted from images or semantic observations.[222] Content-based approaches are based on low-level visual features such as color, shape, or texture.[223] While some content-based image retrieval systems operate by formulating queries submitted by users, others "offer alternatives such as selection from a palette or sketch input."[224] By comparing the query against the images in the database, the system returns images with similar values.[225] This is sometimes referred to as a "hit list." [226]

[57] While semantic observations can be searched by keyword, the linguistic cues used to describe an object,[227] "[o]ne of the oldest-established means of

[221] *See generally* C. H. Chen, et al., HANDBOOK OF PATTERN RECOGNITION AND COMPUTER VISION (3rd ed.).

[222] Akhbardeh, *supra* note 220, at 2.

[223] *See* John Eakins & Margaret Graham, *Content-Based Image Retrieval*, 39 JISC TECH. APPLICATIONS PROGRAMME 26 (1999) *available at* www.jisc.ac.uk/uploaded_documents/jtap-039.doc.

[224] *Id.* at 23. *See also* R. Brown, et al., *Design of a Digital Forensics Image Mining System available at* http://eprints.qut.edu.au/2274/1/2274.pdf. ("Search-by-example is a common practice whereby an image is supplied and the system returns images that have features similar to those of the supplied image.").

[225] Eakins, *supra* note 223, at 23.

[226] *See* Zeno Geradts & Jurrien Bijhold, *Overview of Pattern Recognition and Image Processing in Forensic Science*, 1 ANIL AGGRAWAL'S INTERNET J. FORENSIC MED. & TOXICOLOGY (2000) *available at* http://www.geradts.com/anil/ij/vol_001_no_002/paper005 html ("...it is important that the user has a hit list (the order of the most relevant image matches that are displayed) that is reliable.").

[227] Eakins, *supra* note 223, at 39. *But see* Ryutarou Ohbuchi, et al., *Retrieving 3D Shapes Based On Their Appearance*, PROC. 5TH ACM SIGMM WORKSHOP ON MULTIMEDIA INFORMATION RETRIEVAL (Nov. 2003) *available at* http://portal.acm.org/ citation.cfm?id=973272 ("It is also extremely difficult to describe by words shapes that are not in the well known shape or semantic categories. It is thus necessary to have a content-based search and retrieval systems for 3D models that are based on the features intrinsic to the 3D models, most important of which is the shape.").

accessing pictorial data is retrieval by its position within an image."[228] The latter method provides for queries to look for objects with defined spatial relationships in images.[229] For this reason, image databases are searched differently than textual databases, where words are stored as author defined character strings.[230] Search engines that are "capable of using both text and image features for retrieval, will become commonplace within the next few years."[231] But because 3D images are compilations of 2D measurement data,[232] the comparison of 3D images with 2D shapes is possible with present technology.[233]

[58] The establishment of a robust database of pertinent fire patterns and their related fuel packages will allow for fire artifacts to be quantifiably compared with known exemplars. The goal is for the fire investigator to be able to access all pertinent data within the view of a solitary model.[234] By permitting external data

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[228] Eakins, *supra* note 223, at 24.

[229] *Id.*

[230] *Id.* at 9.

[231] *Id.* at 48.

[232]Matthias Liedmann & Gottfried Frankowski, *Fast 3D Measurement Of Forensics And Trace Analysis*, INFO BULL. SHOEPRINT/TOOLMARK EXAMINERS, Jun. 2001 at 25.

[233] *See generally* Mohamed Chaouch & Anne Verroust-Blondet, *Enhanced 2D/3D Approaches Based on Relevance Index for 3D-Shape Retrieval* (2006) *available at* http://www-rocq.inria fr/~ verroust/chaouch-Enhanced2D3DShapeRetrieval.pdf ("We present a new approach for 3D model indexing and retrieval using 2D/3D shape descriptors based on silhouettes or depth-buffer images.). *But see* Eakins, *supra* note 223, at 24 ("Shape matching of three-dimensional objects is a more challenging task – particularly where only a single [2D] view of the object in question is available. While no general solution to this problem is possible, some useful inroads have been made into the problem of identifying at least some instances of a given object from different viewpoints. One approach has been to build up a set of plausible [3D] models from the available [2D] image, and match them with other models in the database. Another is to generate a series of alternative [2D] views of each database object, each of which is matched with the query image. Related research issues in this area include defining [3D] shape similarity measures, and providing a means for users to formulate [3D] shape queries.").

[234] *See, e.g.*, Shi-Kuo Chang, et al., *Smart Image System*, U.S. Patent No. 5974201 (issued Oct. 26, 1999) ("As a reslt of [the] characteristics of image information, evolving information systems strive to reduce the access time for a user to go from one image display to another, and to permit the unitary usage of image information in a heterogeneous distributed environment."); Jarek Gryz, et al., *3D Crime Scene Acquisition, Representation and Analysis*, 10–11 *available at*

to be associated with the 3D scans, such as semantic observations or lab reports, the user can view this information or associate additional information to the image.[235] Matching scans can be compared in virtual space against other scans, as graphically overlapping on the screen, to identify the degree of similarity between the two.[236] This can also be accomplished mathematically by utilizing "geometric transformations such as scaling, rotating, and translation."[237] For example, the texture of the items, including the "uniformity, density, coarseness, roughness, regularity, intensity, and directionality of discrete tonal features and their spatial relationships," could also be evaluated.[238]

[59] Currently, fire pattern analysis is consistent with traditional notions in forensics, where conclusions are based on the experience of the investigator rather than true statistics.[239] As forensic databases continue to develop, this subjective approach is being replaced by conclusions drawn from more objective

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http://vgrserver.cs. yorku.ca/~jenkin/paper s/2008/csibook.pdf ("The client interface must provide the user with the ability to easily interact with and modify the data . . . A user may retrieve an object from a database and modify it in various ways . . . access and manipulation methods to support analysis of the scene data for investigators . . . providing the data they require in a quick and easy to understand manner.").

[235] *See, e.g.*, Anna Topol, et al., *Generating Semantic Information from 3D Scans of Crime Scenes* (May 2008) *available at* http://www2.computer.org/portal/web/csdl/doi/10.1109/CRV.2008.27.

[236] *See* Zeno Geradts, *Content-Based Information Retrieval from Forensic Image Databases* 13, *available at* http://www forensic.to/Dissertation.pdf*; see also* W. Bruschweiler, et al., *Analysis of Patterned Injuries and Injury-Causing Instruments With Forensic 3D/CAD Supported Photogrammetry (FPHG): An Instruction Manual for the Documentation Process*, FORENSIC SCI. INT'L 132, 130, 138 (2003) ("The objects in question can then be moved against each other arbitrarily on the screen – depending on the questions to be answered – in order to compare them and possibly establish their congruence . . . On-screen one-to-one fit-and-match experiments with objects to be correlated to one another can be performed in virtual space, thus preserving the integrity of the original objects").

[237] Zeno Geradts & Jurrien Bijhold, *Data Mining in Forensic Image Databases*, at 3–4, http://www.google.com/url?sa=t&source=web&ct=res&cd=2&ved=0CBMQFjAB&url=http%3A%2F%2Fciteseerx.ist.psu.edu%2Fviewdoc%2Fdownload%3Fdoi%3D10.1.1.11.7626%26rep%3Drep1%26type%3Dpdf&ei=mwO5S8PsBsOBlAeGmeCXCg&usg=AFQjCNG9GCCdKEPj7RBUAhTlAx4gBCspJQ&sig2=jHRMVTvc9LHBXB0Wv9DurQ.

[238] Geradts, *supra* note 236, at 10.

[239] *Id.* at 2–3.

statistics.[240] Similarly, the use of computers to processes vast amounts of forensic data,[241] will allow for fire pattern analysis to become more objective. By permitting the comparison of individual fire patterns, comprehensive forensic pattern databases will increase the reliability of an investigators conclusion.[242] Furthermore, coordinating with existing fire test and arson databases will provide investigators with a better understanding of the properties of artifacts left after a fire.[243]

F. Anticipating the Future

[60] The high-tech future of fire investigation is on the horizon.[244] Three-dimensional scanning is proving to be the way in forensic investigation.[245] Three-

[240] *Id*. at 3.

[241] Nicola Senin et al., *Three-Dimensional Surface Topography Acquisition and Analysis for Firearm Identification*, J. FORENSIC SCI., Vol. 51, No. 2, 282, 282 (Mar. 2006).

[242] Beyler, *supra* note 85, at 53 ("[The record of] information would serve to not only assess the test variability, but also provide additional model validation benchmarks. The database will not only provide a much better understanding of fire performance, but also give invaluable specific results against which structural fire design and analysis tools can be validated and calibrated."); *see also* U.S. Dept. of Justice, *supra* note 137, at 12 ("Needs: Database management . . . Databases: physical material being tested . . . results of the tests analytical data.").

[243] U.S. Dept. of Justice, *supra* note 137, at 49. *See generally id.* at 19 ("The SFPE Committee on Standard on Calculating Fire Exposures to Structures has compiled a database of 139 compartment fire tests. This database was used to evaluate the appropriate furnace exposure . . . the fuels in these tests ranged from wood cribs, to furniture, to plastics."); Donald G. Robinson, *U.S. Bomb Data Center: A Central Source for Explosives Incident Information*, THE POLICE CHIEF (Feb. 2009) *available at* http://policechiefmagazine.org/magazine/index.cfm?fuseaction=display_arch&article_id=1728&issue_id=22009 ("The U.S. Bureau of Alcohol, Tobacco, Firearms, and Explosives (ATF) has been collecting, storing, and analyzing records on explosives and arson incidents since 1975. In 1996, the ATF Arson and Explosives National Repository Branch was established to satisfy a congressional mandate for the secretary of the treasury to establish a national repository of information on arson and explosives incidents . . . shall consolidate all of the Department's arson and explosives incident databases, including, but not limited to, the FBI's Automated Incident Reporting System and ATF's Bomb and Arson Tracking System, into a single database.").

[244] *See* Madrzykowski, *supra* note 8, at 19 ("After taking digital images of the room and loading them into your strap-on portable computer, you "stitch', the separate images together to form a virtual fire room. Assigning a reference dimension to your image allows the computer to develop an input file for a mathematical fire simulation. You continue to refine your digital image,

dimensional databases are improving accuracy, precision, variability, and objectivity.[246] Indeed, "the significance of 3D methodologies and their potential is explicitly recognized by the National Institute of Justice (NIJ) and the Office of Law Enforcement Standards (OLES) of the National Institute of Standards and Technology (NIST)."[247]

[61] As 3D scanning equipment becomes more affordable, accessibility will increase.[248] It is imminent that these techniques together with other visual and laboratory examination will enable more productive fire investigations, by improving quantitative and qualitative analyses.[249]

III. EMERGING 3D IMAGING TECHNOLOGY AND ADMISSIBILITY

[62] In general, digital images are analogous to photograph for legal purposes. Lawyers are familiar with the necessity that a photograph be authenticated through testimony verifying that it is a fair and accurate representation of what it

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defining surfaces so that the computer model attaches values, such as ignition temperature or heat release rate per unit area, to each. Next, identify the doorways, hvac vents and windows to complete the geometry of the model. Trace the demarcation lines of thermal damage on the image. Finally, define an ignition source; place the ignition fire and press the submit button input fire to a remote computing site and the model is analyzed. A series of potential solutions to your problem is downloaded to your portable computer for you to watch. The fire simulations help you visualize what may have happened, which may lead to a best fit" scenario or guide you in continuing your investigation. Sounds far fetched? Even impossible?").

[245] *See* Tom Shelley, *Tom Shelley Reports on the Growing Application of 3D CAD to Engineering and Human Forensics* (Feb. 17, 2009), http://www. eurekamagazine.co.uk/article/17221/3D-simulation-solves-crimes-and-accidents.aspx.

[246] Michael J. Thali, et al., *VIRTOPSY – Scientific Documentation, Reconstruction and Animation in Forensic: Individual and Real 3D Data Based Geo-Metric Approach Including Optical Body/Object Surface and Radiological CT/MRI Scanning*, J. FORENSIC SCI., Vol. 50, No. 2, 428, 439 (Mar. 2005).

[247] Bachrach, *supra* note 162, at 1253.

[248] S.A. Blackwell, et al., *3-D Imaging and Quantitative Comparison of Human Dentitions and Simulated Bite Marks*, INT. J. LEGAL MED., 121: 9–17, 16 (2007).

[249] R. A. Schroeder & R. B. Williamson, *Post-Fire Analysis of Construction Materials—Gypsum Wallboard*, FIRE AND MATERIALS, May 2, 2000 at 167, 177.

purports to be, and through testimony that the photographic apparatus was functioning appropriately at the time the photograph was taken.[250] The fair and accurate standard has gained common judicial recognition as the contemporary authentication standard for conventional photographic images.[251] Today, even though there are issues related to digital photographs which make authenticating digital photographs more difficult, there has not been much change to the standard.[252] As a result, there is a "dangerous but common precedent that digital versions of routinely accepted traditional evidence do not require additional scrutiny despite the fact that they are the result of new technological processes."[253]

A. Authentication

[63] Before being admitted into evidence, a photograph must first be considered both relevant and authentic.[254] "The Federal Rules do not differentiate between digital and analog photographs, so relevance and authenticity are determined in the same manner for both."[255]

[64] The standards for authenticity are enforced to guarantee that the photos admitted into evidence are what they claim to be. Depending on what the photograph is being used for, the court may employ different levels of scrutiny

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[250] *See* Joe Kashi, *Authenticating Digital Photographs as Evidence: A Practice Approach Using JPEG Metadata*, LAW PRACTICE TODAY, June 2006, http://www.abanet.org/lpm/lpt/articles/tch06061.shtml.

[251] *See id.*

[252] *See* Peter A. Lynch, *Digital Cameras and the Fire Investigator: A Trap for the Unwary?*, http://www.interfire.org/features/camera.asp.

[253] Guthrie & Mitchell, *supra* note 177, at 681.

[254] Erin E. Kenneally, *Confluence of Digital Evidence and the Law: On the Forensic Soundness of Live-Remote Digital Evidence Collection*, 2005 UCLA J.L. & TECH. 5 at ¶ 14 ("The standards for the admissibility of evidence are relevance, authenticity, and reliability").

[255] Zachariah B. Parry, *Digital Manipulation and Photographic Evidence: Defrauding the Courts One Thousand Words at a Time*, 2009 U. Ill. J.L. Tech. & Pol'y 175, 184 (2009).

when determining its authenticity.[256] Should the photograph be used to prove a fact, the court will require a higher amount of accuracy and reliability.[257]

[65] Federal Rule of Evidence 901 compels the authentication of writings and recordings, and specifically asserts that "[t]he requirement of authentication or identification as a condition precedent to admissibility is satisfied by evidence sufficient to support a finding that the matter in question is what its proponent claims."[258] Moreover, Federal Rule of Evidence 901(b) offers further guidance for proper methods of authentication which include but are not limited to:

> (1) the testimony of a knowledgeable witness;
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> . . .
>
> (4) a review of distinctive characteristics in context of the circumstances;
>
> . . .
>
> (9) [and by] "evidence describing a process or system used to produce a result and showing that the process or system produces an accurate result.[259]

Additionally, photographs may be admitted under the "silent witness" theory.[260] This theory permits "photographs offered for their independent probative value to be self-authenticating such that they do not require witness testimony as to their

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[256] *See* Kashi, *supra* note 250.

[257] *See id.*

[258] FED. R. EVID. 901.

[259] FED. R. EVID. 901(b).

[260] Christine A. Guishan, *A Picture is Worth a Thousand Lies: Electronic Imaging and the Future of the Admissibility of Photographs into Evidence*, 18 RUTGERS COMPUTER & TECH. L.J., 365, 369 (1992).

accuracy. Prior to admission of a photograph under this theory, the court requires proof that the photograph has not been altered."[261]

[66] The Federal Rules of Evidence also express a preference for original material when dealing with a photograph; a requirement known as the best-evidence rule.[262] Under limited circumstances, however, duplicates are permissible.[263] "In general, the trial court enjoys wide latitude in admitting or rejecting such replicas, illustrations and demonstrations and in controlling the manner of presentation and whether or not particular items are merely exhibited in court or actually received in evidence."[264] Advances in photography have impressed courts such that photographic evidence is generally favored, "often according it substantial weight."[265]

[67] Even prior to widespread usage of digital cameras, the application of existing rules of evidence to the authentication of digital photography has been controversial because all images are subject to alterations that are potentially undetectable.[266] Digital images are easier to manipulate than traditional

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[261] *See* Witkowski, *supra* note 147, at 280–81.

[262] *See* FED. R. EVID. 1002.

[263] *See* FED. R. EVID. 1003; *but see* Parry, *supra* note 255, at 187–88 ("Some legal experts consider that a digital image should be limited to the version of the image contained on the disk drive of the camera, before being uploaded; others consider the image on the floppy drive or compact flash card good enough. In practice, however, almost any digital image, no matter how many generations down the family tree from the "original," is considered an original for purposes of the best-evidence rule because exact copies can be made of digital files without any loss of quality between generations.").

[264] *See* Rodd v. Raritan Radiologic Assoc., 860 A.2d 1003, 1009 (N.J. Super. Ct. App. Div. 2004).

[265] *See* Madison, *supra* note 149, at 705; *but see* Witkowski, *supra* note 147, at n.35 ("Just when a scientific principle or discovery crosses the line between the experimental and demonstrable stages is difficult to define. Somewhere in this twilight zone the evidential force of the principle must be recognized, and while courts will go a long way in admitting expert testimony deduced from a well-recognized scientific principle or discovery, the thing from which the deduction is made must be sufficiently established to have gained general acceptance in the particular field in which it belongs.").

[266] *See generally* David P. Nagosky, *The Admissibility of Digital Photographs in Criminal Cases*, in FBI LAW ENFORCEMENT BULL. (Dec. 2005) *available at* http://www.fbi.gov/publication/lcb/2005/dec05leb htm ("At its October 18, 2002, meeting in Seattle, Washington, the

photographs and digital manipulation is more difficult to detect.[267] Moreover, software to manipulate digital images is typically included with computer operating systems and new digital cameras.[268] Some cameras, however, produce images that are self-authenticating.[269] "[C]urrent digital cameras contain enough non-evident metadata to detect most alterations,"[270] and many courts and

Advisory Committee on the Federal Rules of Evidence considered the concerns of commentators who argue that digital photographs should not be admitted under current evidentiary rules . . . The committee held a preliminary discussion on whether to amend Rule 901, the authentication requirement, or if a new rule proved necessary to deal with digital photographs. Ultimately, the committee members were skeptical of the necessity of a new rule and felt that Rule 901 'was flexible enough to allow the judge to exercise discretion to assure that digital photographs are authentic and have not been altered.' However, the committee did direct its reporter to 'prepare a background memorandum on the use of digital photographs as evidence" so that it could consider changes to the rules in the future due to its "interest in assuring that the rules are updated when necessary to accommodate technological changes.'); *see also* Maria Aspen, *Ease of Digital Photo Alteration Adds a Hurdle for News Outlets*, THE NEW YORK TIMES, *available at* http://nytimes.com/2006/08/14/technology/14iht_photoshop.2476151.html?r=1.

[267] *See* Witkowski, *supra* note 147, at 271–72 ("Digital images are highly susceptible to manipulation. Manipulation, as distinct from enhancement, consists of changing the elements of a photograph or image by changing the colors, moving items from place to place on the image, or otherwise altering the original image. Individuals without training or specialized equipment may easily manipulate digital images. In fact, users do not even need specialized software to manipulate images; the same programs that allow users to view images or adjust contrast also allow users to cut and paste items with a click of the mouse. Digital camera users also have a greater opportunity to manipulate images than those using traditional cameras because digital camera users process the image themselves, while traditional camera users generally take the film to a professional developer to produce the prints.").

[268] *See* Parry, *supra* note 255, at 182 ("Tools for manipulating digital images can come at little or no cost to the consumer: image manipulation software is included free with operating system software and is often included with a new digital camera.").

[269] *See generally* Nikon, Digital SLR Camera Nikon D700, http://Nikon.com/about/news/2008/0701_d700_01.htm (last visited Apr. 2, 2010).

[270] *See* Joe Kashi, *supra* note 250; Eric R. Harlan *The Litigator's Guide to Metadata*, 3 PROOF (Summer 2007) *available at* www.abanet.org/litigation/committees/trialevidence ("The advisory committee note to the 2006 Amendments to Federal Rules of Civil Procedure 26(f) refers to metadata as 'information describing the history, tracking, or management of an electronic file.' . . . [And it] also speaks of 'embedded data' such as draft language, editorial comments, or other deleted material 'automatically included in electronic files but not apparent to the creator or to readers . . . the image file's metadata will likely contain information about the camera model used

opposing counsel utilize these "digital fingerprints" to authenticate digital files.[271] The enhancement of digital images is another area of contention that must be considered whenever innovative forensic imaging approaches are employed.[272] Accordingly, challenges to these types of evidence should be anticipated.[273]

B. Reliability

[68] Although digitally enhanced imaging usually meets the reliability standard of Federal Rule of Evidence 702,[274] the introduction of digital images as a product

to take the photograph, the original date and time the image was taken, the focal length, and whether any programs were used to enhance or alter the image.'").

[271] *See generally* Ladas & Parry, LLP, Federal Rules to be Amended to Address Electronic Discovery, http://ladas.com/BULLETINS/2006/FRCPElectronicDiscovery.shtml.

[272] *See* Scientific Working Group Imaging Technology (SWGIT), § 5, *Recommendations and Guidelines for Digital Image Processing Standard Operating Procedures*, 10 *available at* http://www.theiai.org/guidelines/swgit/guidelines/sec5_2_20060109.pdf ("The purpose of image processing procedures is to apply processing techniques intended to enhance, restore, and/or compress digital images. The successful introduction of processed images as evidence in a court of law is dependent upon the following four legal tests as they relate to the processing: reliability, reproducibility, security, and discovery."); *but cf.* James I. Keane, *Prestidigalization: Magic, Evidence and Ethics in Forensic Digital Photography*, 25 OHIO N.U.L. REV 585, 591(1999) ("Artistic touches such as smudging, blurring, and other aesthetic enhancements that have their place in photojournalism and photo "art" books have almost no place in forensic photography.").

[273] *See* Cherry, *supra* note 178, at 42–43 ("All enhancements should be challenged as they require very precise steps and newly trained personnel may find them difficult to understand or implement."); *cf.* Witkowski, *supra* note 147, at 289–90 ("First, the proponent must show that the camera and storage medium could technologically support the image offered . . . Second, the proponent must show that the operator was competent to operate the digital camera . . .Third, the proponent must show that the digital image is a true representation of the scene . . . A fourth authentication requirement is that an "original" image be preserved for the court.").

[274] *See generally* Nooner v. State, 907 S.W.2d 677, 686 (Ark. 1995) ("Reliability must be the watchword in determining the admissibility of enhanced videotape and photographs, whether by computer or otherwise."); State v. Hayden, 950 P.2d 1024, 1027 (Wash. App. 1998) ("Image enhancement techniques are not designed to create detail but to improve images for human interpretation."); State v. Hartman, 754 N.E.2d 1150, 1165 (Ohio 2001) ("The trial court accepted the reliability of digitally enhanced fingerprint evidence, finding that the use of the computer in this instance is no different than . . . would be the use of an overhead projector, microscope, a magnifying glass or anything else like that that would enhance an expert's ability to make his determination."); Kennedy v. State, 853 So.2d 571, 573 (Fl. Dist. Ct. App. 2003) ("However, as noted above, neither the LCV or the Morhitz program alter the evidence, create evidence, or

of new 3D technologies will likely require expert witness testimony to guarantee its reliability.[275] "In other words, attorneys who wish to introduce this kind of evidence will need to establish that the digital image is in fact what it purports to be."[276] As noted by one scholar:

> Reliability usually depends on the reliability of the underlying scientific principle; the reliability of the technique or process that applies to the principle; the condition of the instrument used in the process; adherence to proper procedures; the qualifications of the person who performs the test; and the qualifications of the person who interprets the results.[277]

[69] The proffered expert will likely be tasked with defending the scientific legitimacy of the techniques utilized. Testimony should be presented concerning "the qualifications of the individual enhancing the photographs and the type of software used to perform the enhancement."[278] Therefore, this individual should be an imaging science expert with the qualifications to ". . . testify in matters pertaining to light, optics, physics and chemistry of imaging, photogrammetry, and the psychophysics of human visual perception in the interpretation of images."[279]

[70] In *State v. Swinton*,[280] the Connecticut Supreme Court addressed authentication issues when digitally created or altered evidence is offered for

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change the comparison methods used to match the evidence to a suspect. As the trial court aptly noted, they are both merely enhancement tools . . . .").

[275] *See generally* Paul Reedy, et al., *Digital Evidence–A Review: 2004 to 2007*, 419 in 15TH INTERNATIONAL FORENSIC SCIENCE SYMPOSIUM INTERPOL-REVIEW PAPERS (Oct. 2007).

[276] *See* Guthrie & Mitchell, *supra* note 177, at 674.

[277] *See* Witkowski, *supra* note 147, at n.35.

[278] *See* Campbell, *supra* note 145, at 15.

[279] *See* Hyzer, *supra* note 118, at 11–8.

[280] 847 A.2d 921 (Conn. 2004).

evidentiary purposes, and constructed a factors test for the authentication of evidence generated or enhanced by a computer.[281] This test considered whether:

> (1) the computer equipment is accepted in the field as standard and competent and was in good working order, (2) qualified computer operators were employed, (3) proper procedures were followed in connection with the input and output of information, (4) a reliable software program was utilized, (5) the equipment was programmed and operated correctly, and (6) the exhibit is properly identified as the output in question.[282]

Furthermore, the *Swinton* court required expert witness testimony concerning the above-noted factors "by a person with some degree of computer expertise, who has sufficient knowledge to be examined and cross-examined about the functioning of the computer."[283] In this instance, while one segment of the evidence passed muster, some of the enhancements were not admitted since the State had failed to establish a proper foundation by satisfying all of the above-noted factors.[284]

[71] "The clear lesson from *Swinton* is that a party must be prepared to present a witness knowledgeable about the program and the process used to create the enhanced digital images."[285] "Although the witness need not be an "expert" in the

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[281] *See id.* at 942.

[282] *See id*.

[283] *See id*. at 941.

[284] *See* Campbell, *supra* note 145, at 15 ("Although the witness was present while the enhancements were made, he could not answer questions that inquired whether the programs used were accepted in the field as standard and competent, whether proper procedures were followed in connection with the input and output of the information, whether the program was reliable for forensic application, or whether the equipment was programmed and operated correctly. Accordingly, the court found that the State had not provided the proper foundation for the admission of the overlay digital images and ruled that their admission into evidence was error.").

[285] *Id.*

technology or have created the images personally, he or she must be able to provide credible testimony on the factors identified by the court."[286]

CONCLUSION

[72] Fire investigative methodologies in general, and fire pattern analysis particularly, suffer from reliability deficiencies due to an abundance of undereducated practitioners, an underdeveloped scientific foundation, and obsolete capture and documentation methodology. The judiciary has not been an effective gatekeeper in disallowing suspect and unsupported fire-related testimony. Skepticism is mounting, and change is inevitable.

[73] As it has in other areas of criminal law, 3D technologies will be used to document the spatial characteristics of fire scenes and multi-resolution databases will be utilized for the analysis of evidence. Digital imaging technology, utilized by properly trained and educated investigators, will simultaneously revolutionize fire investigations and blunt future criticisms. And computer analysis will enhance the reliability and accuracy of fire pattern analysis.

286 *See id*. at 18.