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Empirical and virtual experiments: reconstruction of an extraordinary death

Introduction

In recent years, both nationally and internationally, there has been increasing emphasis on the role of cooperation between different specialized fields in proving crimes. This trend is well illustrated by the European Network of Forensic Science Institutes (ENFSI), which encourages experts to cooperate through proficiency tests and to study efficient organization of work processes in order to extract and utilize the maximum amount of information from evidence during examinations[1,2]. In Hungary, forensic experts working at the Hungarian Institute for Forensic Sciences (HIFS) continuously seek opportunities for cooperation between specialized fields, primarily in connection with major crimes, where joint work is essential to

[1] Zampa, F. – Bandey, H. – Bécue, A. – Bouzaid, E. – Branco, M. J. – Buegler, J. – Kambosos, M. – Kneppers, S. – Kriiska-Maiväli, K. – Mattei, A. – Zatkalikova, L. (2024): ENFSI 2022 multidisciplinary collaborative exercise: organisation and outcomes. Forensic Science International: Synergy 2024. 8 100465.

[2] Kiss, István: The system of opportunities for expert cooperation in international and national practice. Police Studies. 2024/1-2. 110-119.

address questions that span multiple areas of competence and overlap between individual areas of expertise[3,4,5].

According to legal provisions in Hungary, it is the expert's task and duty to become familiar with all data related to the case that is necessary for the fulfillment of their duties, and experts have the opportunity to present their findings in the form of joint or joint expert reports[6,7]. In investigating cases that raise case-specific problems, it is essential to fully utilize the possibilities provided by law, and to maintain close cooperation between the investigating authority and experts, as well as between experts from different specialized fields. The following case study clearly demonstrates that expert involvement is extremely important in cases where the investigating authority has doubts about an unusual death. One of the most difficult questions, both during on-site death examinations and in expert practice, is determining whether an injury or set of injuries caused by blunt force trauma is the result of an accidental event, an accidental fall (e.g., age-related gait instability, loss of balance, illness, dizziness, stroke, sudden cardiac death, etc.) or an intentional, third-party action or abuse (e.g., hitting, pushing). This is because injuries characteristic of blunt force trauma can occur both from being hit with a blunt object and from impact with a hard surface. Both processes can be understood physically as a type of collision, thus

[3] Lontai, M. – Kosztya, J.S (2023): The challenges of institutional expertise in the light of technological development. [Az intézményi szakértés kihívásai a technológiai fejlődés tükrében.] Ügyészek lapja 2023. 30(5-6) 75–90

[4] Fülöp, P. – Ujvári, Zs – Petrétei, D. – Kiss, I. - Dudás-Boda, E. – Metzger, M. – Fullár, A. (2023): Modern tools and possibilities of forensic expert illustration. [Az igazságügyi szakértői szemléltetés modern eszközei és lehetőségei.] Ügyészek lapja 2023. 30(5-6) 91–102

[5] Fullár, A. – Dudás-Boda, E. (2024): Examination methods at the intersection of forensic anthropoligist and forensic mark expert competences in Hungarian practice. Police Studies 2024.

[6] Act XC. of 2017 on büntetőeljárásról XXXI. fejezet A szakértői vizsgálat 192. § (1), [Act XC of 2017 on Criminal Procedure Chapter XXXI Expert Examination Section 192 (1)]

[7] Act XXIX. of 2016 on the Forensic Experts, 2. § (2).

showing many similarities. Differentiation is particularly difficult if the incident occurs in a home environment and potential perpetrators are family members, as DNA testing offers no meaningful assistance in these cases.

In these cases, determining the cause and manner of death is of paramount importance, which is informed by data from the death scene examination and subsequent autopsy. Examining bone fractures and soft tissue hemorrhaging alone, without knowledge of detailed circumstances and other scene alterations, can hinder the investigation of injury causes and, in extreme cases, lead the procedure to a dead end. For medical experts, extensive injuries and bone fractures easily raise the question of whether they occurred during an accidental fall or intentional abuse. If any doubt arises regarding the mechanism of injury formation, it is advisable to involve experts with different competencies in the procedure. The possible mechanism of injury formation and the most likely sequence of events should be examined in collaboration with experts skilled in physics and the analysis of marks and bloodstains, who can contribute their knowledge and experience to clarify questions involving overlapping areas. As a result, they can clarify circumstances based on classical mechanics laws, and by jointly analyzing other traces in a complex manner, they can support or refute the accidental or third-party nature of the incident. Additionally, medical experts – primarily in the courtroom – may face expectations to separately comment on the complex formation mechanisms of injuries occurring nearly simultaneously due to various loads (e.g., pulling, compression, bending, shearing, twisting) and the magnitude of the forces creating them. Therefore, in such complex cases, it is required that experts reliably – based on scientific methods and credibly – evaluate possible processes.

At the plenary session of the ENFSI SoC EWG conference held in Budapest in October 2024, we presented the expert aspects of the first case in Hungary where experts from multiple fields used empirical and virtual model experiments to reconstruct an unusual death.

Case study

According to initial reports, an elderly lady was found dead in her own home, where she was allegedly alone following her hospital treatment. The woman, who died under suspicious circumstances, was discovered by her daughter's boyfriend at the bottom of the stairs leading from the upper floor to the ground floor, with bleeding injuries. According to the discovering witness, he turned the woman's body, which was lying on its left side perpendicular to the stairs, onto her back for resuscitation. Given her health condition, he believed his girlfriend's mother had become ill on the stairs and consequently fallen.

In Hungary, according to health regulations, criminal police procedures are required in all cases of an extraordinary death. This can occur under criminal procedure rules if the extraordinary death results from a crime, including both intentional and negligent commission. These can be various crimes ranging from intentional homicide to negligent homicide and crimes causing death beyond intent, such as causing fatal traffic accidents, endangerment through violation of occupational rules, or forms of public endangerment resulting in death. If no crime is suspected, the criminal police still conduct procedural actions, but under administrative law rules, similar to regulatory inspections in other legal areas. Under administrative law procedures, it's also possible to conduct scene investigations, interview witnesses, and gather extensive data. Despite the differences in procedural rules, the police work according to the same professional standards and investigate every unusual death so that the resulting documents and evidence could later be used in a potential murder investigation. It's also important to note that murder cases are investigated by the territorial police, while unusual deaths are investigated by the local police. In the latter case, the territorial police may closely monitor and supervise the local police's work.

For this case, it's also important that Hungarian criminal law punishes death caused beyond intent, meaning when the perpetrator intentionally causes injury but the victim "accidentally" dies from it, with imprisonment

from 2 to 8 years. Completely negligent homicide, when the perpetrator sees the possible outcome but recklessly trusts it won't occur, or when they don't see the possible consequences because they failed to exercise due care (attention), is punishable by imprisonment from 1 to 5 years. Intentional homicide can be punished with imprisonment from 5 to 15 years. In cases with aggravating circumstances (such as: profit-seeking motive, minor victim, defenseless victim, particularly cruel commission, etc.), homicide is punishable by imprisonment from 10 to 20 years or life. In Hungary, actual life imprisonment without parole exists.

The medical expert performing the official autopsy detected injuries on the body (left frontal region hemorrhage, broken facial bones, broken ribs, hyperextension fracture of thoracic vertebrae) early in their examination that raised doubts about the accidental nature of the death. For this reason, they ordered a forensic autopsy and, together with another medical expert, conducted a complete exploratory examination. However, the medical experts' findings alone were not sufficient to modify the police procedure to a criminal case. The investigating authority examined the crime scene data and the discovering witness's testimony, and further peculiarities emerged regarding the case, such as the position of the body relative to the stairs or the bloodstains found in the vicinity of the body. To clarify these disturbing findings, additional experts needed to be involved. The investigating authority provided an opportunity for an additional scene examination, witness hearing at the scene, and a concurrent expert examination. This allowed the appointed medical expert, physicist, mark examiner, and bloodstain pattern analyst to examine the original scene, conduct model experiments, discuss their results together, and apply photogrammetry methods for precise scene documentation.

Following the on-site examinations, the experts provided a joint expert report within the framework of their official appointment, still within the administrative procedure. The data detailed in the "Examination Results and Professional Findings" chapter of the report clearly indicated that, alongside the examined accident mechanism, third-party involvement

might have played a role in connection with the fall from the stairs. Based on the expert report, criminal proceedings were initiated, in which the discovering witness was now a suspect. The statements made during his on-site interrogation were examined by the acting experts in a new joint expert report, and their accuracy was verified using virtual model experiments. The investigating authority concluded the case with an indictment for aggrevated murder, where the expert reports served as the sole evidence alongside the suspect's testimony. All experts involved in the case were heard together by the court during a separate trial day in the presence of the defendant and their defense counsel, where they presented their results and model experiments in digital presentation form. The court of first instance sentenced the defendant to 19 years in prison and 10 years of disqualification from public affairs for murder committed against a defenseless person, which sentence was upheld by the appeals court[8,9].

Bloodstain Pattern Analysis and On-site Empirical Model Experiments

Analyzing the crime scene photographs, the mark examiner and the bloodstain pattern analyst involved in the investigation found spatter stains and flow patterns on the victim's right arm that only partially corresponded with the discovering witness's account (area marked with red arrow in Fig. 1A). On the victim's face and chest, as well as in the blood pool on the floor beside the body, transfer stains were visible that suggested the body was turned from a prone position to a supine position (areas marked in white and black in Fig. 1A). Additionally, the location and direction of impact patterns on the stair-side of the blood pool, along with spatter stains on the

[8] Source: https://jogkodex.hu/doc/8727149
Accessed: 03.07.2025
[9] Source: https://kekvillogo.hu/egy-porzsak-miatt-oltotta-ki-anyosa-eletet-a-tatabanyai-ferfi-19-ev-fegyhazat-kapott/
Accessed: 03.07.2025

stairwell wall, indicated that the already-formed blood pool had been subjected to multiple forces (area marked in yellow in Fig. 1A and Fig. 1B).

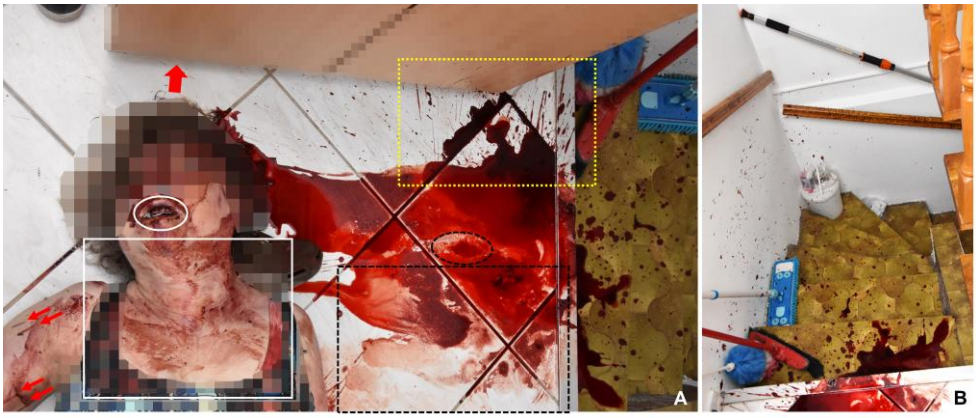

Figure 1.
A: Bloodstains on the body (marked in white and red) and in its surroundings (marked in black) indicate that the victim was moved from a prone position to a supine position. Evidence of blood impact pattern is visible on the edge of the blood pool on the floor (area framed in yellow). The victim's head is located at the edge of the dresser. B: Blood spatter on the wall and staircase near the body. (Original crime scene photographs)

During the scene examination conducted by the forensic experts, the discovering witness demonstrated the victim's position at the time of discovery and the circumstances of moving the body using a dummy. Subsequently, the experts modeled the process of turning the body onto its back using both the dummy and a person matching the victim's body measurements, following the discovering witness's account and based on the results of the bloodstain pattern analysis (Fig. 2.). According to the discovering witness's demonstration, both the dummy's and the model person's head aligned with the centerline of the cabinet door behind the body, contrary to the victim's head position, which was aligned with the edge of the cabinet (Fig. 1A. and Fig. 2A-B.). This position did not explain the bloodstains found on the victim's arm, face, chest, or the floor and wall. In the experiment where the victim's rotation began from a prone position, based

on the bloodstains, the final supine position of the body showed similarities with the victim's condition during the death scene examination, with the head aligning with the cabinet's edge (Fig. 1A. and Fig. 2C-E). The prone starting position explained the bloodstains found on the face, chest, and right arm, assuming that the body with bleeding injuries had its right arm resting on the first step of the staircase leading to the basement before being turned onto its back. However, the evidence of force impacts visible on the edge of the blood pool around the head (impact pattern) and the multiple spatter stains visible on the walls were not explained by the mechanisms of falling from the stairs and being turned onto the back.

Figure 2.
A-B: The victim's initial and final positions as demonstrated by the discovering witness. C-E: Phases of the expert reconstruction model experiment based on bloodstain pattern analysis. (The author's own recordings.)

The crime scene photographs were also examined by a physics expert. The fall to the location described by the discovering witness is not qualitatively supported by the laws of Newtonian mechanics, which in itself raises

the possibility of third-party involvement. Due to the complexity of the case, empirical model experiments were planned within the framework of an on-site expert examination, where the accidental nature described by the discovering witness was examined as a null hypothesis, and the possibility of third-party involvement as an alternative hypothesis. It was necessary to empirically examine how the body could have reached its final state under different initial conditions (from which step, from what body position, with what initial velocity).

The experts examining the null hypothesis dropped a forensic dummy in the model experiment to simulate a possible illness, and pushed it to simulate stumbling from the staircase at the incriminated scene toward the ground floor. Accordingly, the dummy was thrown from several possible positions, such as being dropped and pushed face-forward and backward from different steps, and being pulled toward the railing. Testing the alternative hypothesis, the dummy was pushed face-forward from the kitchen toward the hallway. The results showed that the most likely process for the body reaching its discovery position – in light of the data available at the time of the examination – could have been falling or being pushed face-forward from the kitchen door (Fig. 3A-B.). Furthermore, in two cases – when pushed backward from the sixth step (Fig. 3 D-E.) and when pulled down by the arm from the third step – the dummy landed on the hallway floor in a position similar to that described by the discovering witness. However, according to the medical expert's report, injuries typically caused by reflexive support during a possible stumbling or loss of balance (palm, elbow, and knee injuries) were absent. From a medical expert's perspective, the absence of these injuries may indicate that the deceased had lost consciousness before reaching the ground. Based on these findings, the null hypothesis could therefore be refuted, as the body, when released or pushed from various positions, could not have landed in its discovery position merely by falling from the stairs.

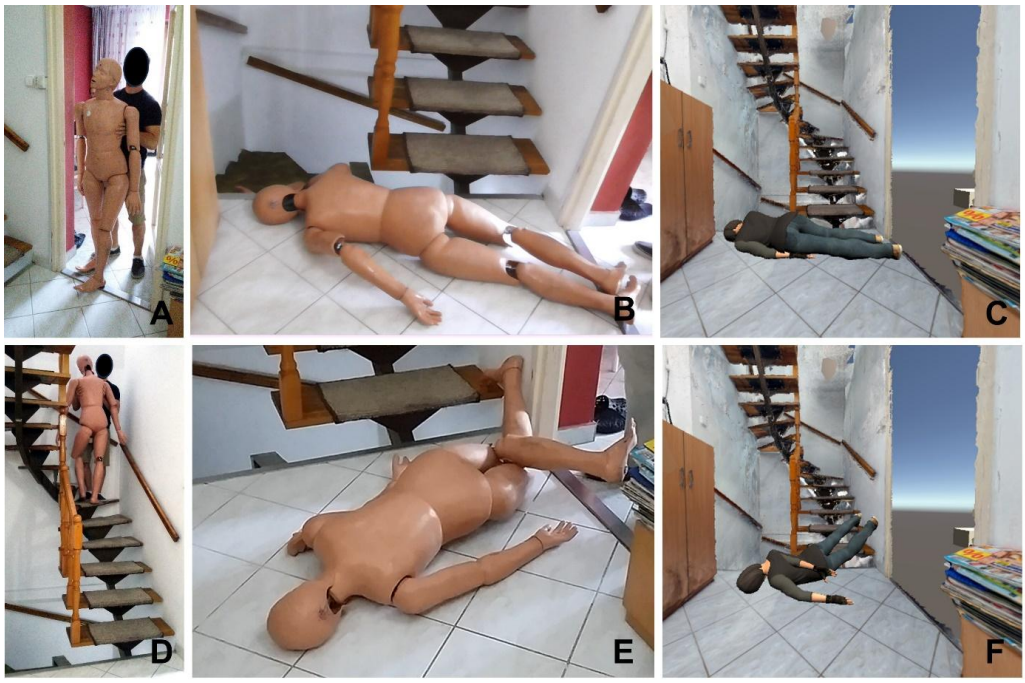

Figure 3.
Empirical and virtual model experiments at the scene. A-C: Initial and final states of pushing the victim face-forward from the kitchen door. D-F: Initial and final states of pushing the victim backward from the 6th step of the stairs. (The author's own photographs.)

Photogrammetry and Virtual Model Experiments

Photogrammetry has long been used in the film and gaming industries, among others, to create accurate, realistic digital models of various buildings and objects. It is a three-dimensional imaging process where specialized imaging software determines the approximate three-dimensional structure of objects using photographs taken from different viewpoints and applying mathematical methods, with the resulting three-dimensional models quite accurately reflecting the geometric structure of the reconstructed

objects [10]. Photogrammetry can be an effective tool in forensic practice for photographing bodies and reconstructing crimes and accidents [11]. Three-dimensional models can be created using photogrammetry software. In Hungary, for the first time during this case's on-site expert examination, alongside empirical experiments, we created three-dimensional models of the stairwell (the railing, stairs, and steps) and relevant parts of the hallway using photogrammetric methods, using RealityCapture (Version 1.2.0.16813) photogrammetric imaging software. The three-dimensional model of the scene details was scaled based on measurements taken at the scene and the sizes of marker stickers placed on the wall, approximately reflecting the actual geometry.

The tool for implementing the action in a virtual environment was the Unity (v2021.2) graphics engine and the Ragdoll Wizard integrated into the application, which helped bring the photogrammetric 3D model of the scene to life. We imported the photogrammetric model of the original scene into Unity and placed a virtual dummy (ragdoll) in this model to reproduce the fall from the stairs, with body segments adjusted to match the victim's body mass. Thanks to Unity's physics engine (PhysX engine), physical parameters can be freely adjusted in the software, such as the magnitude of gravitational acceleration, elastic properties of objects involved in collisions, coefficient of restitution, friction, air resistance, and the magnitude, direction, and point of application of external forces in three spatial directions. We also created a custom script that allowed us to apply forces of any magnitude and direction to any point on the ragdoll's body surface, enabling simulation of the forces experienced by the victim.

[10] Ujvári, Zs. – Metzger, M. – Gárdonyi, G. (2023): A consistent methodology for forensic photogrammetry scanning of human remains using a single handheld DSLR camera. Forensic Sciences Research 2023. 8(4) 295–307

[11] Metzger, M. – Újvári, Zs. – Gárdonyi, G. (2020): Application of photogrammetry for forensic purposes: reconstruction of locations, corpses, objects in three dimensions. [A fotogrammetria kriminalisztikai célú alkalmazása: helyszínek, holttestek, tárgyak rekonstrukciója három dimenzióban.] Belügyi szemle 2020. 68(11) 57–70

We repeated the empirical model experiments previously conducted with the forensic dummy in a realistic virtual environment by dropping a ragdoll with the same body weight as the deceased 10 consecutive times from different positions, modeling collapse while standing on different steps in the digitized stair landing. As a final result, we obtained the same results as the empirical model experiments, namely that when pushing the body face-forward from the kitchen door, the dummy reached the deceased's discovery position (Fig. 3C.), while pushing from the stairs resulted in at most a similar position (Fig. 3F.).

During the investigative phase of the criminal proceedings, the experts had to examine the sequence of events demonstrated by the suspect during their on-site interrogation. Since the previous empirical and virtual model experiments encompassed the main elements of the sequence of events described by the suspect, and the physical processes during the empirical experiments showed good agreement with the virtual model experiment results thus validating each other, it was sufficient to only investigate in the virtual space and refine the initial conditions with the statements made in the suspect's testimony. The suspect presented the version that the victim was walking down the stairs in front of him when the victim suddenly stopped around the fourth step from the bottom and looked back. At this point, the suspect, moving downward with momentum, couldn't stop in time and pushed the victim, causing them to fall face-forward onto the floor. When the victim landed on their left side, they weren't bleeding yet but also didn't move. According to his account, panic and rage overtook him, he kicked the body several times, then lifted the victim's head to check for signs of life and dropped it back. The physics expert modeled these statements in the virtual stairwell. He examined the accidental push as approximately 900 N and the intentional push as approximately 1665 N force (impact), applied to the victim's head, back, leg, or hip area. After considering the possibilities, he finally concluded that the victim's fall from the stairs could have been caused by a sudden push, hit, kick, or foot-pushing either to the head while the body was half-turned to the right and backward, or to the hip area

while facing forward (Fig. 4.). Subsequently, the experts jointly concluded that the victim did not suffer the fatal injuries during the fall from the stairs, but afterward during abuse on the floor tiles, during the hyperextension of the head and impacts of the face with the ground. Therefore, the victim was alive when they suffered the abuse on the ground, with the suspect repeatedly kicking the helpless victim, kneeling on their back, hyperextending their upper body, and forcefully slamming their head into the floor tiles at least twice. During the autopsy, the medical experts documented injuries on the victim's body consistent with both the fall from the stairs as described by the suspect (Fig. 4E-F.) and the subsequent abuse. The objective evidence presented by the experts and the sequence of events inferred from these, together with the suspect's testimony, were collectively sufficient to prove the charge of aggravated murder.

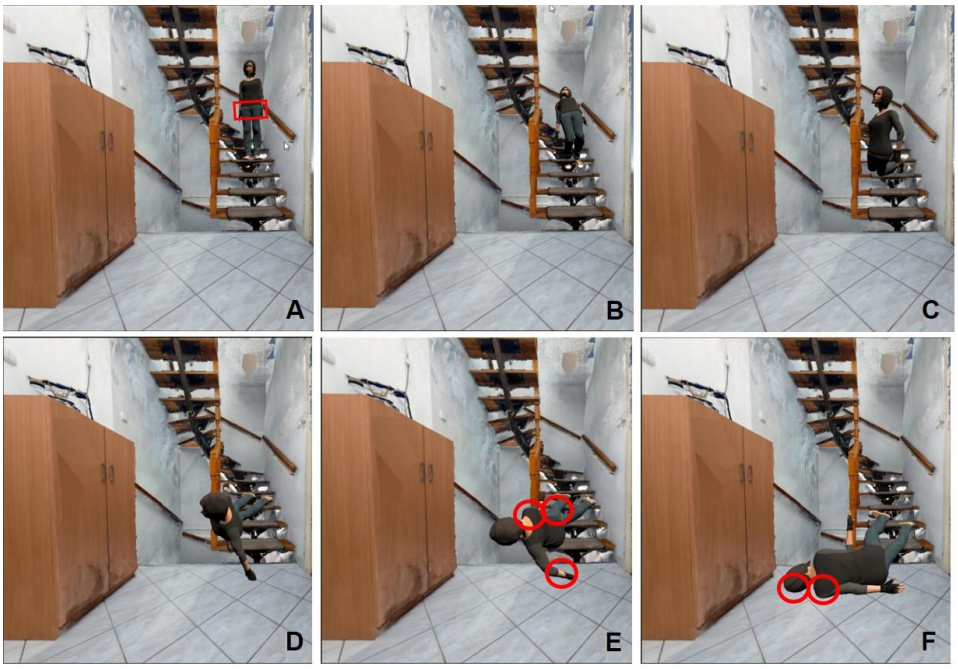

Figure 4.
A-F: The most likely moments of the victim's fall from the stairs in the virtual model experiment. Based on the suspect's statements during the on-site interrogation and the results of expert examinations, the suspect pushed the victim in the hip area while coming down the stairs, and the victim fell to the floor. In moments E and F, we have circled the body parts that were injured and documented during the autopsy when making contact with the stairs (right thigh, right shoulder, right upper arm, left forearm) and the floor (left shoulder, left forehead). (The author's own recordings.)

Discussion

The case detailed above provided numerous innovations from both the appointing authority's and experts' perspectives. For the investigating authority, it is always challenging to quickly find clear evidence during the investigation of an unusual death whether intentional actions or accidents

led to the deceased's death, especially when no substantial physical evidence is available. The close cooperation between multiple expert fields and the innovative, multi-perspective approach to the incriminated event opened new dimensions where the joint expert report, as the sole means of evidence, could form a self-contained logical chain serving as the basis for a conviction. The further significance of the case presented in this study is that it demonstrates how effective communication between the appointing authority and experts can help solve a case that began as an unusual death and concluded as aggravated murder.

The case also helps highlight how multifaceted experts' work is and what complex perspectives and thinking it requires even within a single case. At the time of the first expert appointment, only the crime scene data and the discovering witness's testimony were available, so the experts operated in „investigative mode." At this stage, they primarily conducted diagnostic examinations, providing objective data regarding the sources of discovered evidence. Later, summarizing the results, they examined possible processes (mechanism of reaching the ground) at the activity or action level. During the second expert appointment, they switched to "evaluative mode." This means that during the examination, they sought to answer whether the suspect's statements aligned with the injuries on the victim's body, the bloodstains, and the model experiments simulating the fall from the stairs.

The case's uniqueness provided an excellent opportunity to test and try the photogrammetry method in practice (through its application in virtual model experiments). Its criminalistic (in a narrower sense forensic) significance lies in its versatile applicability at any time during administrative or criminal proceedings. In this case, we focused on the repeatability of expert experiments conducted to examine complex movements and the quick and cost-effective possibility of testing different scenarios. This required the most accurate possible three-dimensional model of the original stairwell that we could implement in a software environment where the laws of physics could be realistically simulated. We chose the Unity game de-

sign software. First, we had to verify the correctness of the software's embedded physics engine to determine if the virtual model experiment results were reliable, acceptable, and applicable as an examination method in similar cases. Thus, from this perspective, this case can be interpreted as a kind of validation process. Comparing the final results of empirical and virtual experiments, it can be said that the forensic dummy can be replaced with the ragdoll. Based on our examinations, Unity's physics engine correctly simulates the movement of bodies colliding with other objects under gravitational force (however, it's important to emphasize that it does not simulate their deformation). Experiments with the virtual dummy falling from the steps of the virtual stairwell in the gravitational field produced equivalent results to experiments conducted in reality. In forensic practice, this enables the verification of testimony content and testing of action details using Unity Ragdoll Wizard in other cases as well.

In light of the outlined results, it can perhaps be boldly stated that every innovative effort, high professional knowledge, teamwork, and a bit of luck were needed to make this case provable. We hope our work can serve as an example and help in numerous similar cases in the future!

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