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Monte Carlo and Biophysics Analysis in a Criminal Trial

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Abstract—In this paper a real court case, held in Italy at the Court of Nola, in which a correct physical description, conducted with both a Monte Carlo and biophysical analysis, would have been sufficient to arrive at conclusions confirmed by documentary evidence, is considered. This will be an example of how forensic physics can be useful in confirming documentary evidence in order to reach hardly questionable conclusions. This was a libel trial in which the defendant, Mr. DS (Defendant for Slander), had falsely accused one of his neighbors, Mr. OP (Offended Person), of having caused him some damages. The damages would have been caused by an external plaster piece that would have detached from the neighbor's property and would have hit Mr DS while he was in his garden, much more than a meter far away from the facade of the building from which the plaster piece would have detached. In the trial, Mr. DS claimed to have suffered a scratch on his forehead, but he never showed the plaster that had hit him, nor was able to tell from where the plaster would have arrived. Furthermore, Mr. DS presented a medical certificate with a diagnosis of contusion of the cerebral cortex. On the contrary, the images of Mr. OP's security cameras do not show any movement in the garden of Mr. DS in a long interval of time (about 2 hours) around the time of the alleged accident, nor do they show any people entering or coming out from the house of Mr. DS in the same interval of time. Biophysical analysis shows that both the diagnosis of the medical certificate and the wound declared by the defendant, already in conflict with each other, are not compatible with the fall of external plaster pieces too small to be found. The wind was at a level 1 of the Beaufort scale, that is, unable to raise even dust (level 4 of the Beaufort scale). Therefore, the motion of the plaster pieces can be described as a projectile motion, whereas collisions with the building cornice can be treated using Newtons law of coefficients of restitution. Numerous numerical Monte Carlo simulations show that the pieces of plaster would not have been able to reach even the garden of Mr. DS, let alone a distance over 1.30 meters. Results agree with the documentary evidence (images of Mr. OP's security cameras) that Mr. DS could not have been hit by plaster pieces coming from Mr. OP's property.

Keywords—Biophysical analysis, Monte Carlo simulations, Newton's law of restitution, projectile motion.

I. Introduction

IN THIS paper there is presented a real court case held in Italy at the Court of Nola (sentence n. 1010/2020 issued on June the 15th of 2020 at the Nola Court by a Single Judge of the first instance in monocratic composition and filed on June the 19th of 2020). In the trial, Mr. DS (Defendant for Slander) was accused of slander; in particular, Mr. DS would have falsely accused, by means of a summons, his neighbor, Mr. OP (Offended Person), of having caused him damage for which he would have demanded undue compensation. The damage consisting, as stated by Mr. DS in the trial, in a scratch on his forehead with blood loss would have been caused by external pieces of plaster that would have detached from the property of Mr. OP and would have reached Mr. DS in his garden, more than a meter far away from Mr. OPs building facade.

In the trial, Mr. DS was not able to provide the external plaster pieces that had hit him and stated that he had not seen from which point of Mr. OP's building these pieces of plaster had detached. On the other hand, he provided a medical certificate with the diagnosis of a contusion of the cortex (cerebral) with no mention of an exposed intracranial injury, without loss of consciousness (head injury with no concussion). The diagnosis was made without any diagnostic tool. Furthermore, in the medical certificate there was no mention of a scratch on the forehead with blood loss, in contrast with what was stated in the trial by Mr. DS.

In this paper, a description of the legal problem together with the physical situation will be first presented. Monte Carlo [1] simulations will be conducted to verify if the possible trajectories of the plaster pieces were compatible with the alleged accident. Finally, a biophysical analysis will then be conducted to verify whether the declared injuries were plausible or not.

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II. The Legal Problem

In the trial, Mr. DS was accused of slander; in particular, Mr. DS would have falsely accused, by means of a summons, Mr. OP of having caused him damage for which he would have demanded undue compensation.

The harm would have been caused by external plaster pieces that would have detached from Mr. OP's property and would have reached Mr. DS in his garden, more than a meter away from Mr. OP's building facade, injuring him in his head.

In order to understand the dispute and the physical problem, the physical situation is represented in the Fig. 1. The detachment point, denoted by a circle in Fig. 1, was stated in the trial as the most likely.

III. Physical and Biophysical Analysis

As it is known, a body, dropped, falls under the action of the weight force along the vertical. To allow the body to move horizontally, a horizontal velocity component shall

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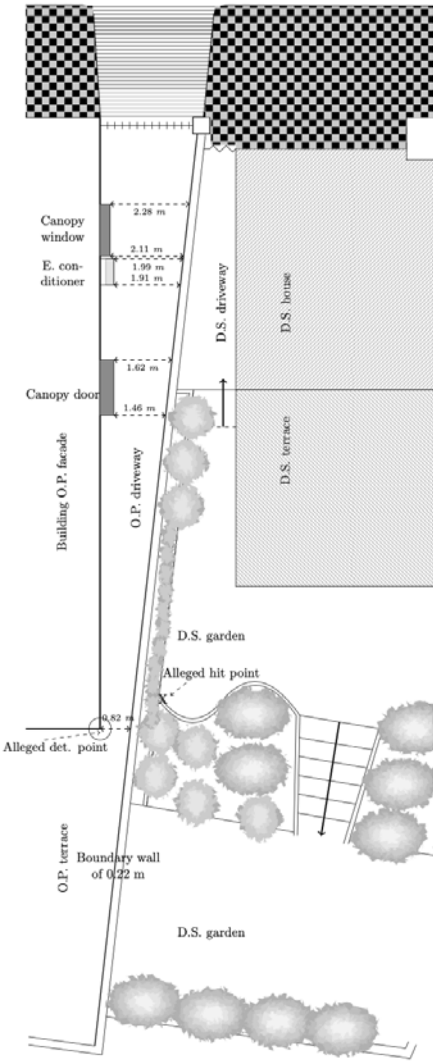

Fig. 1 Facade of Mr. OP's building from which the alleged plaster pieces would have been detached. The X indicates the point where Mr. DS would have been hit by the plaster pieces. This point is well over 1.30 m from the detachment point on the facade, denoted by a circle

be impressed at the initial velocity. External plaster pieces can acquire a horizontal component of velocity if they are either transported by a strong gust of wind and/or if they undergo some impact during the fall. On the website of the Meteorological Observatory of the University of Naples Federico II, it is possible to consult monthly reports on climate parameters in the province of Naples, where the alleged accident would have occurred, recorded over the years. In particular, it is possible to download reports with daily detail of the winds [2]. From one of these reports, it results that the day of the alleged accident, the 2nd of February 2015, wind had an average speed of $1\ mph$ $(1\ mile/hour\ =\ 1.6\ km/h)$ and a maximum speed of $10\ mph$ $(\ 16.0\ km/h)$.

To get an idea of wind intensity, one has to refer to the Beaufort scale, represented by numbers from 0 to 12. On this scale, the average speed of $1\ mph$, recorded the day of the alleged accident, corresponds to number 1, light air (wind direction shown by smoke drift but not by wind vanes), whereas the maximum $10\ mph$ wind, recorded on the same day, corresponds to number 3, gentle breeze (leaves and small twigs in constant motion; light flags extended).

Wind speed for which slight structural damage may occur to buildings, thus capable of transporting external plaster pieces, is at number 9, strong/severe gale (slight structural damage: chimney pots and slates removed, with wind speeds typically between $75\ km/h$ and $88\ km/h$) or, at the most, at number 7, high wind (whole trees in motion and inconvenience felt when walking against the wind -speed $(50\ km/h\ -\ 61km/h)$), and number 8, gale/fresh gale, (twigs break off trees; generally impedes progress, speed $(62\ km/h\ -\ 74km/h)$). Therefore, on the day and at the hour of the alleged accident, the wind was such that it did not affect the trajectories of the alleged external plaster pieces. The wind conditions were confirmed by the images of Mr. OP's security cameras.

A. Trajectory and Range

It only remains to assume a collision with the cornice, as assumed in the trial (Fig. 2). Friction with air can be neglected because, in any case, it has a braking effect and therefore a shortening of the horizontal range. Therefore, the only force acting on an external plaster piece during its motion is the weight force. Its equations of motion will be:

$$\vec{F}_g = m\vec{g} = m\vec{a}_c \quad (1)$$

$$\vec{\tau}_e = 0 = \ I_u\ \frac{d\vec{\omega}}{dt} \quad (2)$$

where $\vec{a}_c$ is the acceleration of the center of mass, $\vec{g}$ the gravitational acceleration, $\vec{\tau}_e = 0$ is the $\vec{F}_g$ moment relative to the center of mass C, I_u is the moment of inertia relative to an axis u passing through C, and $\vec{\omega}$ is the angular velocity around the u axis.

Equation (1) describes the motion of the center of mass C, that is where the plaster pieces may arrive, whereas (2) describes rotations about the center of mass C, and in particular tells us that the rotation speed remains constant. In order to establish if external plaster pieces might have reached Mr. DS in his garden, one has to consider only (1), which allows to estimate the distance that they might have travelled. In Appendix, all calculations about the motion of the center of mass are reported. In particular, a detached external plaster piece moves with a projectile motion until it collides with the cornice. Taking a very conservative assumption, it will be assumed that the external plaster piece hits a point of the cornice other than the foot of the perpendicular to the point of contact (that is a point of coordinate other than $x_i = \delta$ in Fig. 3). In that case, the plaster piece must have, at the moment of detachment, a small horizontal component of the velocity, v_{0x}, that can be determined according to the coordinate of the collision point x_i. It will also be made the further conservative assumption that the external plaster piece had an initial vertical component of velocity $v_{0y} = \beta v_{0x},\ \beta \in [-1, 1]$ of the same order of magnitude as v_{0x}, and always as a function of x_i in Fig. 3.

During the collision, the force of reaction due to the plane of the cornice, an impulsive force of contact, acts. The effect of

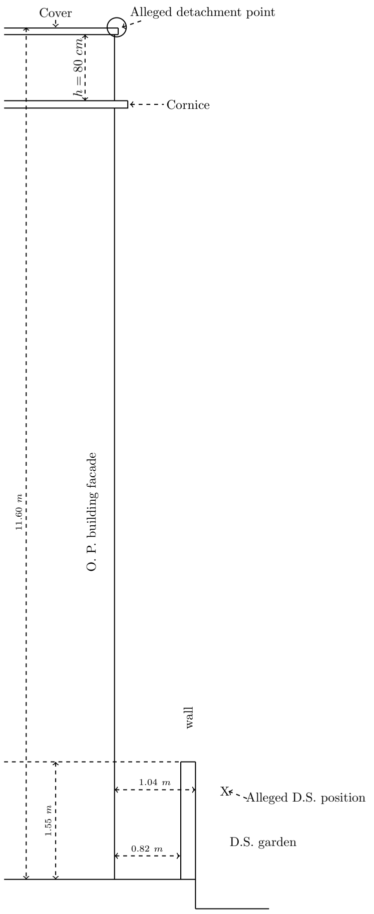

Fig. 2 Profile of Mr. P.O.s building at the minimum distance from the boundary wall. An X indicates the point where Mr. DS would have been hit by the plaster piece, point which is not on the same plane. This point is well over 1.30 m from the facade of the building from which the plaster pieces would have detached

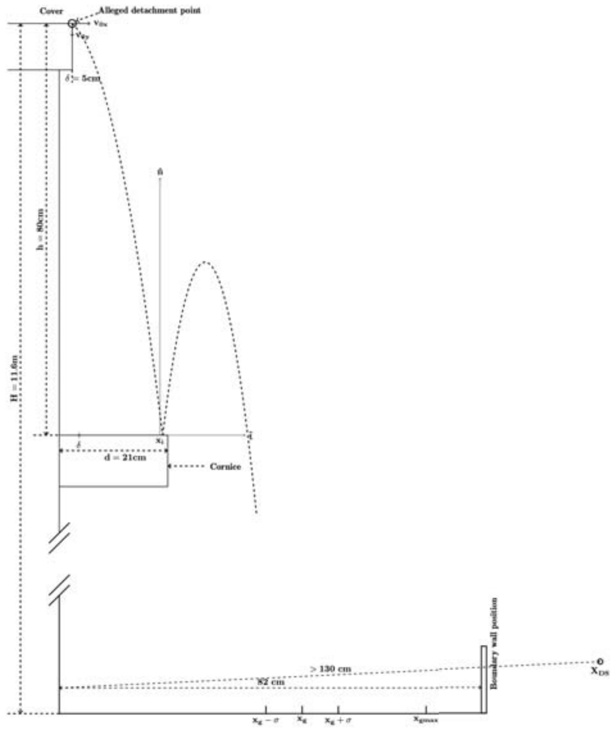

Fig. 3 Monte Carlo simulations results. Estimated range $x_g = (47cm \pm 7cm)$, with a maximum $x_{gmax} = 71\ cm$. In dashed, as an example, calculated trajectory for $x_i = 18\ cm,\ \beta = -0.9,\ e_t = e_n = 0.65$. Alleged Mr. DS position, $X_{DS} > 130\ cm$, is not in scale. From Monte Carlo simulation, Mr. DS could not have been hit by the alleged detached external plaster pieces

the collision is described by normal and tangential restitution coefficients (e_n, e_t COR), which, for plaster materials, are in the range $0.09 \leq e_n \leq 0.18$ and $0.01 < e_t \leq 0.10$ ([3]–[5]). However, in a very conservative approach, simulations will be conducted assuming $e_t, e_n \in [0.35, 0.65]$, that is, assuming that an external plaster piece dropped from a 1 meter height bounces up to a height of between $[12.2\ cm, 42.2\ cm]$ (a new tennis ball dropped from 1 meter height bounces up to 53 cm, being the COR of a tennis ball roughly equal to 0.731 [6]).

After the collision, the plaster piece resumes its projectile motion subject only to the weight force. All equations are described in Appendix, in which the final range, x_g in (25), is calculated in terms of x_i, β, e_t, e_n parameters. Due to x_g dependence on the parameter values, Monte Carlo [1] simulations were conducted by sampling randomly parameters in their intervals of variability. In particular, x_i was obtained by generating draws from a uniform distribution in the interval $[5\ cm, 21\ cm]$; in a very conservative approach, e_t, e_n were obtained by generating draws from a uniform distribution in the interval $[0.35, 0.65]$; finally, β was obtained by generating draws by a normal distribution with mean 0 and standard deviation 0.3 in the interval $[-1, 1]$.

Ten million simulations were conducted and results were $x_g = (47cm \pm 7cm)$, with a maximum $x_{gmax} = 71\ cm$. Monte Carlo simulations show that the external plaster pieces would not have even reached the separation wall and then could not have hit Mr DS, who was beyond the wall at not less than 1.30 m from the facade (Fig. 3).

B. Biophysical Analysis

A falling body constitutes a projectile whose potential damage is related to the kinetic energy and parameters connected to it. The study and research on projectiles whose effect is related to kinetic impact energy is highly developed in the field of forensic science. There are numerous scientific publications in this field, and the effects are described in terms of well-defined physical parameters. In particular, the studies and assessments of potential damage are based on four physical parameters [7]:

1) impact kinetic energy K_{ie}, in $Joule(J)$:

$$K_{ie} = \frac{1}{2}mv^2, \tag{3}$$

where m is the projectile mass and v its speed;

2) momentum $\vec{p}$, in $kg\ m/s$:

$$\vec{p} = m\vec{v}, \tag{4}$$

where m is the projectile mass and $\vec{v}$ its velocity;

3) the impact surface area S, in mm^2;
4) the energy density J_e in J/mm^2 defined as the ratio of the impact kinetic energy and the impact surface area:

$$J_e = \frac{K_{ie}}{S}. \tag{5}$$

Several scientific studies have shown that there are threshold values for some of these parameters below which there is no risk of damage. Particularly important, in this regard, is the threshold of energy density, J_{eth}, equal to 50% of $0.1 J/mm^2$, i.e.:

$$J_{eth} = 0.05 J/mm^2. \tag{6}$$

For energy density values below J_{eth}, there is no risk of damage to the skin [8],[9]. Furthermore, there is the threshold of the impact kinetic energy, K_{ieth} :

$$K_{ieth} = 40J, \tag{7}$$

which is the K_{ie} threshold in order to have a risk of damage such as bruises, abrasions, concussions and damage to superficial organs [10].

An external plaster piece is made of dry concrete, whose density, in a conservative approach, can be assumed $\rho = 2300\ kg/m^3$ (mean concrete density), and it would have had a thickness δ of about $\delta = 2\ cm$, and mass $m = \rho\, V = \rho\, \delta S$, being S its surface area. Evidently:

$$K_{ie} = (\frac{K_{ie}}{m})m = (\frac{K_{ie}}{m})\rho\delta S \tag{8}$$

$$J_e = K_{ie}/S = (\frac{K_{ie}}{m})\rho\delta \tag{9}$$

where $(\frac{K_{ie}}{m})$ in (J/kg) is the impact kinetic energy for unit mass of an external plaster.

From Monte Carlo simulations, impact kinetic energy for unit mass was $\frac{K_{ie}}{m} = (108\ J/kg \pm 1\ J/kg)$ with a maximum of 109 J/kg, so that, by (8), J_e would had be, at most:

$$J_e = 0.005 J/mm^2 < J_{eth} = 0.05\ J/mm^2 \tag{10}$$

The energy density value that an external plaster piece would have had at the impact is $J_e = 0.005\ J/mm^2 < J_{eth}$, an order of magnitude lower than the threshold value of $J_{eth} = 0.05 J/mm^2$, reported in the scientific literature as a minimum threshold to have some effect on the skin. From (5), (7) and (10) in order for a piece of outer plaster to would have produced abrasion and/or concussion, it would had to have a minimal impact surface of $S \geq K_{ieth}/J_e = 80\ cm^2$, which is in contrast to what was stated in the trial by Mr. DS, who had not been able to find any external plaster piece in his garden, and in contrast to the fact that the photos of the facade of Mr. OPs palace do not show such large voids at the point of detachment of the external plaster.

IV. Conclusion

From physical and biophysical analysis, it is not credible that Mr. DS may have been hit and wounded by an external plaster piece detached from the facade of Mr. OPs building. In addition, conclusions obtained by the Monte Carlo simulations and biophysical considerations are compatible with other documentary elements, such as photos of the facade of the building and images of the security cameras of Mr. OP, filed at the trial.

Appendix
Equation of Motion

Let the detachment velocity $\vec{v}_d$ be denoted by $\vec{v}_d = v_0\hat{\imath} + \beta v_0\hat{\jmath}$. The equations of motion up to the impact with the cornice will be:

$$v_x(t) = v_0 \tag{11}$$

$$x(t) = \delta + v_0 t \tag{12}$$

$$v_y(t) = \beta v_0 - gt; \tag{13}$$

$$y(t) = H + \beta v_0 t - \frac{1}{2}gt^2 \tag{14}$$

where $\beta \in [-1, 1]$. By (14), the instant, τ, in which the external plaster piece bumps the cornice is:

$$\tau = \frac{\beta v_0}{g} + \sqrt{(\frac{\beta v_0}{g})^2 + \frac{2h}{g}} \tag{15}$$

By (12), at the instant τ, $x(\tau) = x_i = \delta + v_0\tau$, so that v_0, as a function of the point of impact, x_i, and of the β parameter, is:

$$v_0 = (x_i - \delta)\sqrt{\frac{g}{2h + 2\beta(x_i - \delta)}} \tag{16}$$

with

$$\beta > -\frac{h}{x_i - \delta} \tag{17}$$

true $\forall x_i \in (\delta, d)$. By (12, 14, 15, 16), the velocity at the instant τ are:

$$v_{x\tau} = v_x(\tau) = v_0; \tag{18}$$

$$v_{y\tau} = v_y(\tau) = -\sqrt{(\beta v_0)^2 + 2hg} \tag{19}$$

For the theory of restitution coefficients, speeds after the collision with the cornice u_x, u_y, are:

$$u_x = e_t v_{x\tau} = e_t v_0; \tag{20}$$

$$u_y = -e_n v_{y\tau} = e_n\sqrt{(\beta v_0)^2 + 2hg} \tag{21}$$

The equations of motion after the collision are:

$$x(t) = x_i + u_x t = x_i + e_t v_0 t \tag{22}$$

$$\begin{aligned} y(t) &= (H - h) + u_y\, t - \frac{1}{2}gt^2 \\ &= (H - h) + e_n\sqrt{(\beta v_0)^2 + 2hg}\; t - \frac{1}{2}gt^2 \end{aligned} \tag{23}$$

By (23), the instant, τ_g, in which the external plaster piece touches the ground is:

$$\tau_g = \frac{u_y}{g} + \sqrt{(\frac{u_y}{g})^2 + \frac{2(H - h)}{g}} \tag{24}$$

and, by (22, 24) the coordinate of the point x_g in which it touches the ground, respect to the facade, is:

$$x_g = x_i + e_t v_0 \tau_g \tag{25}$$

Equation (25), together with (16), (21), (24), allow to calculate the coordinate x_g of the point in which the external plaster piece touches the ground as a function of $x_i \in [\delta, 21\ cm], \beta \in [-1, 1]$ and e_t, e_n.

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