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Article

Mathematical modeling and optimization of workplace illumination in ceramic industries (Iran) using DIALux evo

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Abstract: Introduction: Many detrimental effects on employees' health and wellbeing might result from inadequate illumination in the workplace. Headaches and trouble focusing can result from eye strain brought on by inadequate illumination. The purpose of this study was to simulate and optimize workplace illumination in the ceramic industry. **Materials and methods:** A common Luxmeter ST-1300 was used to measure the illumination in seven workplaces at a height of 100 cm above the floor. DIALux evo version 7.1 software was used to simulate the illumination of workplaces. To optimize the illumination conditions, a numerical experiment design consisting of 16 scenarios was used for each of the workplaces. Four factors were considered for each scenario: luminaire height, number of luminaires, luminous flux, and light loss factor. The Design-Expert program version 13.0.5.0 was applied for developing the scenarios. Finally, by developing quadratic models for each workplace, the optimization process was implemented. **Results:** Every workplace had illumination levels that were measured to be between 250 and 300 lux. Instead of using compact fluorescent luminaires, LED technology was recommended to maximize the illumination conditions for the workers. Following optimization, 376 lux of illumination were visible at each workstation in every workspace. For the majority of the workspaces, the simulated illumination was expected to have a desirability degree greater than 0.9. The uniformity and illumination of the workplace were significantly impacted by the two factors of luminaire height and luminaire count. **Conclusion:** The primary outcomes of this optimization were the environmental, political, and socioeconomic ones, including reduced consumption power, high light flux, and environmental compatibility. Nonetheless, the optimization technique applied in this work can be applied to the design of similar situations, such as residential infrastructure.

Keywords: artificial illuminative system; DIALux evo; 3D luminance maps; compact fluorescent luminaire; design of experiments (DOE); light loss factor; luminous flux

1. Introduction

Maintaining an active and healthy workforce is a critical factor in determining sustained economic and human development (Jain et al., 2024). Organizations and society alike place strategic significance on taking care of the workforce and increasing its ability (mentally, physically, socially, etc.) (Benson et al., 2024; Klimova et al., 2022; Pervukhin et al., 2023). Major developments over the past two decades have given special attention to the sustainability concept of workers' working conditions in industries (Eremeeva et al., 2022). Well-designed spaces with adequate illumination, fresh air, acceptable temperatures, and ergonomic layouts are linked to higher labor productivity and well-being (Glebova et al., 2023). Labor productivity is a critical performance metric that affects a business's profitability and is essential to assessing the operational output and future growth prospects of the organization (Gendler et al., 2023; Korshunov et al., 2023). Productivity is also intrinsically linked to illumination conditions (Fanpu and Hua, 2024; Gridina and Borovikov, 2023). For industrials looking to ensure the best possible working conditions, industrial illumination is a must these days (Bolshunov et al., 2023; Rudakov et al., 2021; Smirniakova et al., 2021). Studies have indicated that certain environmental stresses that are not thermal in nature, including illumination conditions, can also trigger physiological reactions in the body (Gendler et al., 2024; Wang et al., 2024; Zhang et al., 2024a). Be that as it may, it is now widely recognized that accidents in complex man-machine systems are usually caused by the disruption of the optimal conditions of the illumination (Katabaro and Yan, 2019; Linh et al., 2025). Illumination not only provides for human visual demands (picture, vision, contrast), but it also significantly affects physiological parameters (cardiovascular responses, circadian rhythm, hormone regulation), psychological states (mood, productivity, alertness), and both (Hoffmann et al., 2008). Additionally, illumination has a big impact on employees' moods (Roy et al., 2024; Shestakova and Morgunov, 2023). Research has indicated that employees who work in well-lit workplaces tend to be happier and more motivated (Al-Bsheish et al., 2023). On the other hand, dimly illuminated spaces can lower energy levels and cause depressive symptoms (Schledermann et al., 2023).

Providing suitable illumination for the workplace is one of the basic principles of health care management (Veitch, 2006). The Bureau of Labor Statistics estimates that 5250 American workers lost their lives while performing their jobs in 2018, with over 14 deaths occurring per day (Shestakova, 2024). Illumination in an industrial setting becomes a safety issue in addition to a matter of mood and productivity. Workspaces with adequate illumination enable employees to identify and steer clear of possible hazards, lowering the likelihood of accidents. Sufficient illumination, for instance, can prevent mishaps resulting from tripping, falling, or misusing machinery (Kabanov et al., 2021; Kabanov et al., 2023; Kolvakh, 2023). As workers spend a substantial amount of time working, their work performance, health, and well-being can be significantly affected by the illumination quality of workplaces (Barjoee et al., 2024; Sokol et al., 2023). Additionally, task-specific illumination is essential for inspections or activities requiring attention to detail (Nguyen et al., 2024). Inadequate illumination in these places might result in serious mistakes and even accidents (Vetter et al., 2022). Every effort should be made to prevent mishaps at work, and making sure there is adequate illumination is an essential part of these efforts (Giménez et al., 2017; Ru et al., 2023). Industrial illumination fixtures are crucial to the maintenance of a safe and efficient work environment since they are specifically engineered to illuminate huge areas utilized for heavy-duty jobs (Vetter et al., 2022). It affects employee happiness, attentiveness, and productivity while fostering clear vision and precise perception. Guidelines for illumination conditions at work are provided by the European Agency for Safety and Health at Work (EU-OSHA), the Canadian Centre for Occupational Health and Safety (CCOHS), and the Occupational Safety and Health Administration (OSHA) in the United States (Kraneburg et al., 2017). Among other things, these cover maintenance suggestions, illumination design, and illuminance levels. Adhering to these guidelines guarantees adherence to regulations and, thus, enhances safety.

Only a small number of researchers have examined illumination design and technology to improve working conditions; the majority of studies have concentrated on the physiological and psychological impacts of illumination on employees in industrial workplaces (Mannan, 2020). Technology is always pushing the envelope of what is feasible in a number of industries, illumination included. Notably, innovations in illumination technology, together with other technical developments, present new chances to improve efficiency and safety in the industrial world (Moerman, 2023). An atmosphere that is well-lit, safe, and productive can be created by using technological developments in industrial illumination and adhering to established rules. These components have the potential to significantly improve workplace safety when paired with careful installation and ongoing maintenance (Roberts et al., 2023). The quantity and quality of illumination in industrial workplaces over time vary according to the type and duration of use of luminaires, the type of luminaires and related equipment, the reflection coefficients of internal surfaces, and the presence or absence of natural illumination (Li et al., 2024). Every industrial workspace is diverse and requires a particular kind of illumination. These requirements are contingent upon the dimensions of the area, the type of work being done, the operating hours, and even the site (Mannan, 2020).

There are several technical factors to consider when optimizing illumination in industrial environments, including color temperature, illumination output, power consumption, system weight, and functionality (Meng et al., 2016). Visibility and mood are also influenced by the color temperature, which is expressed in Kelvin. Cooler lights (5000 K and above) are ideal for work demanding high attention and alertness since they are vivid and brilliant, mimicking daylight (Roy et al., 2024). Areas that are meant for relaxation or rest may be better suited for warmer colors (3000 K or below), which produce a softer, yellowish light (Meng et al., 2016; Wei et al., 2014). The production of melatonin is influenced by the color rendering index and color-correlated temperature (CCT) of light, which have a significant impact on regulating human circadian, neuroendocrine, and neurobehavioral responses (Nazari et al., 2023; Vetter et al., 2022). These are the two quantitative illumination components that are critically important. In order to meet visual or nonvisual needs, the color rendering index and CCT are crucial for constructing artificial illuminative systems, especially when using fluorescent sources (Wei et al., 2014). It's crucial to think about lighting options that are energy-efficient in addition to maintaining safety. A more ecologically friendly operation and reduced running costs are the results of reduced energy consumption. LED technologies are superior to fluorescent luminaires or conventional high-intensity diodes (HIDs) in terms of illumination quality and energy efficiency (Albu et al., 2023). They also have a reputation for lasting a long time, which lowers the need for replacements.

Iran is known as one of the largest ceramic-producing countries. Over the decades, the gradual development of ceramic industries in Iran has provided employment to many people. These industries are always prone to accidents and full of possible dangers. All of these environments are made much more dangerous by inadequate illumination. Despite the rapidly increasing ceramic industries nationally in Iran, there is no evidence of optimization of lighting conditions. At present, there are no studies on the quantity and quality of artificial illuminative sources in the ceramic industry. A poor illumination situation is depicted in expert studies regarding the working conditions of employees in this sector. In order to promote productivity and wellness, there is a growing need for illumination in the workplace. In terms of industrial applications, simulations can be useful in several aspects for improving the design and integration of illumination in the ceramic industry. Recognizing the increasing necessity to satisfy their needs, optimizing the workers' workspace in terms of both space and illumination is becoming a significant issue. The use of illumination simulation to replace conventional verification methods is growing (Mannan, 2020). The process of simulating the behavior of light in a particular environment with computer software is known as illumination simulation. This may be used to see and examine how light interacts with surfaces and objects in a workplace in a variety of industries. Zemax/OpticStudio, TracePro, Code V, OSLO, ASAP, and other commercial software tools for generic illumination design are designed to simulate, create, and optimize optical components for many applications. While designing illumination schemes can be one of these jobs, these software programs lack dedicated techniques for the design and optimization of illumination systems and were not only designed with the purpose of illumination simulation in homes and offices in mind (Safiullin and Arias, 2024). The chosen tool can be different depending on the task at hand. They also have industrial applications. For instance, simulation and performance analysis call for tools that can replicate real systems as closely as feasible through precise and realistic simulations. In general, illumination simulation gives experts a useful tool to help them decide on lighting design, energy use, and visual impact in different environments. This approach enables us to better predict the visual comfort and subjective state of employees in the workplace (Zhang et al., 2024b). One tactic in sustainable illumination design is the deployment of strong models through computer programs. Illumination simulation offers varying degrees of complexity for different users within the same field, but it is also difficult because of the rigorous criteria to accurately replicate reality (Albu et al., 2023). It can give researchers better and faster ways to compare more complex data that would have taken a long time to get, among many other advantages (Mannan, 2020). Simulations of illumination can be integrated with other building simulations and the design process. Even though computer illumination simulation is becoming widely used in building science, it hasn't been thoroughly reviewed in the literature. It is common practice to compare various models (computer and real-world) to ensure that features or correctness are verified side by side; however, when computer programs are updated or discarded, these assessments become old. In the past decade, numerous studies have employed diverse simulating techniques, each possessing unique benefits and drawbacks. Damour forecasted the behavior of the light within a building envelope and simulated illumination conditions using the Hemera program (Malet-Damour et al., 2017). Roan et al. conducted a study on the prediction model for indoor illumination based on image metrics. Based on the findings of correlation analysis, the study offered a composite metric assessment model that predicted spatial brightness with an accuracy of 0.932, greater than existing prediction models (Ruan et al., 2024). Bai et al. conducted a study with the aim of deep graph learning for spatially-varying indoor illumination prediction. The new illumination representation (DSGLight) in this research was inferred from a single low dynamic range (LDR) image of a limited field-of-view using a graph convolutional network (GCN) and depth-augmented spherical Gaussians (SGs) (Bai et al., 2023). Mahdavi and Mahattanatawe have simulated illumination using the LUMINA module of SEMPER's. The ray-tracking radiosity method is integrated into LUMINA technology. It was employed to compute the amount of power needed for artificial illumination in order to maintain the discrepancy between the needed illuminance and the amount of daylight (Mahdavi and Mahattanatawe, 2003). Lassandro et al. used the 3D model based on the illumination scenarios with various historical-interpretative hypotheses and the reconstruction of the used luminaires (Lassandro et al., 2021). Lin et al. used computer numerical simulation to test and analyze the data on the illumination scheme of a hospital ward, and their results showed that the retrofitted ward illumination improved the uniform glare value (UGR) for patient perspective and the experimenters' comfort assessment (Lin et al., 2024). Perumal and Baharum used a circadian illumination control system using a fuzzy logic controller and light-emitting diode (LED) illumination technology (Perumal and Baharum, 2022). Putrada et al. (2022) reviewed the application of machine learning methods in smart illumination toward achieving user comfort.

Despite the development of numerous control and optimization techniques for industrial illumination systems, there is still a lack of integrated workplace control that takes into account the simultaneous interactions of human, economic, and environmental factors. However, it is necessary to apply building simulation models based on these three factors. On the other hand, in order to simulate, certain programs need commercial codes and a significant amount of processing power. The use of free codes might be feasible, but they require particular illumination design adjustments, which might be laborious and difficult to verify because of the restrictions on the availability of experimental data. Furthermore, outlining contingency strategies based on simulations and predictive statistical models is significant for the field of building illumination design. Additionally, using a predictive statistical model could help with illumination analyses, as the illumination design may provide helpful information to guide the selection of an appropriate contingency plan for each specific deviation. This study's primary goal is to use the DIALux simulation tool in the form of a numerical experimental design to optimize the illumination system used in the ceramic sector. The capacity of the DIALux simulation tool to assess the effects of design modifications and illumination methods is one of its main advantages for the ceramics sector. Stakeholders can use this information to make educated decisions and reduce the risks associated with insufficient illumination.

2. Materials and methods

In this study, the effectiveness of an illuminative system to enhance workers' working circumstances was assessed using simulation and experimental methods. The results were then examined in order to determine whether or not it would be possible to improve both the illumination of the workplace and the well-being of the workers. The investigation was carried out using DIAlux evo software and a numerical experimental design approach. The research workflow is displayed in **Figure 1**.

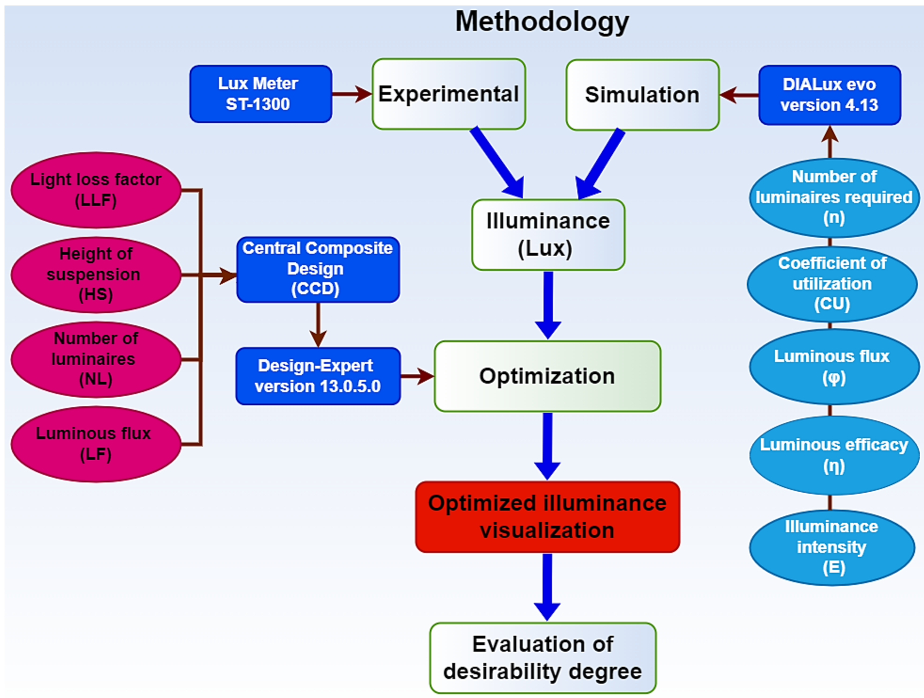


Figure 1. A schematic of the research methodology.

2.1. Selection of location and its characteristics

This study was conducted on workplaces in Iran's ceramic sector. The following details were gathered beforehand in order to optimize the illuminative systems of the workplace: room length (L), room width (W), ceiling height (H_c), suspension height (H_s), working plane height (H_w), color of the ceiling and walls, condition of the windows, presence of air conditioning or fans, surrounding conditions, and kind of workplace. Workplaces are oriented so as to block out natural daylight. **Figure 2** shows the workplaces of the ceramic industry studied. The majority of the working hours in this industry are spent in the seven primary workplaces that make up this sector. The details of each workplace are described below:

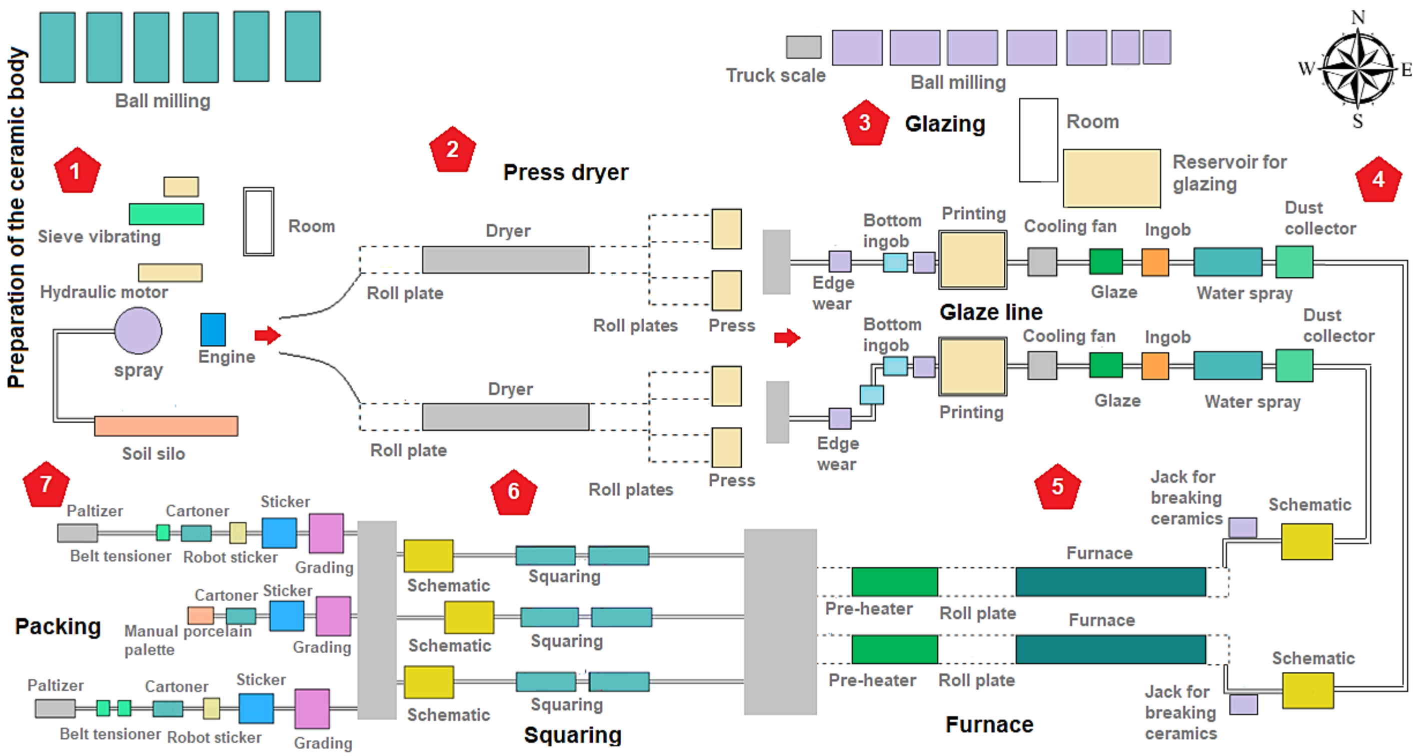


Figure 2. A schematic of the details of the production process in the workplaces of the ceramic industry.

Preparation of the ceramic body: The process of preparing raw materials for ceramic body preparation is carried out in this workplace. The hard raw materials are crushed after being prepared and weighed in accordance with the factory's desired formula to create the body of each product. Following their crushing, the raw materials are homogenized by ball mills with a certain amount of water and lubricants to made into slurry.

Press: After preparing the raw materials in the form of powder, it is turned into a ceramic body by press pressure.

Glazing: A glaze slurry is created in this workplace by combining water with powdered minerals, oxides, and other ingredients. In ball mills, this procedure is carried out. The resulting glazing slurry is kept in tanks for storage.

Glaze line: Applying glaze to the ceramic pieces prior to their final firing is an essential step in the production process of ceramics, and it happens here. The glaze line is usually a component of an automated production system that guarantees ceramics' consistency and efficiency. Depending on the product and desired effect, many application methods, like dipping, spraying, or brushing, can be used to apply the glaze. This process gives the ceramic surface a protective layer in addition to improving its appearance.

Furnaces (Kilns): The most important piece of equipment for firing ceramics is a kiln. It produces the high temperatures required to change and solidify glaze and clay bodies, resulting in long-lasting ceramics. Throughout the production process, the furnace plays a crucial role, particularly during the bisque (first fire) and glaze (last firing after glaze application) firings.

Squaring: Squaring is a finishing technique used in the production of ceramics that entails precisely cutting and shaping ceramics or slabs to produce dimensions that are uniformly square. This stage is essential to guaranteeing uniformity in the ceramics, particularly after fire, when a little amount of shrinkage or warping may happen. Squaring processes include loading, grinding, calibration, water cooling, inspection, and polishing.

Packing: When making ceramics, packing is the last step before the products are finished. Quality control, sorting, protecting the edges and corners, using shrink wrap or straps, cardboard boxes, wooden crates (for large items), pallets, product information, batch information, handling guidelines, destination information, palletizing and wrapping, last inspection, and loading for transportation are all steps in the packing process.

Luminary details: 105 W fluorescent, projector, and LED luminaires make up the current illuminative system in the workplaces. Nonetheless, low-consumption fluorescent luminaires are dominant in the illuminative system of the studied ceramic industry. The percentage of illumination output is roughly 68%. Total luminous flux is around 6300 lumens. An estimated 405 luminaires have been installed in workplaces overall. Seventy-four of these are either burned out or turned off. Almost all luminaires are off during the day. During the second work shift, all luminaires will be turned on.

2.2. Experimental setup

It was ensured that the environment was stable. In other words, there was no sudden change in light. A standard Luxmeter ST-1300 was used in the experimental section to measure all illumination sampling at a height of 100 cm from the floor (equivalent to the height of a work plane). The lux meter was turned on, and its correct calibration was checked in the first step. The lux meter was calibrated using a standard illumination luminaire prior to the measurement. In this manner, the standard luminaire illumination was adjusted to almost equal the distance L between the photocell and the standard luminaire, which is below the operating distance of the illuminative source. After that, the lighting E was determined using the inverse square rule and the ammeter reading that was obtained at each distance. Calculations were made for illumination E and distance $E = I/r^2$. In this manner, the values of luminous flux I were acquired under various illumination conditions, and the illumination calibration curve—a curve representing the change in luminous flux I with illumination E—was produced. The measuring phase started after the calibration procedure was finished. The lux meter sensor in this case was positioned on the work plane's surface. The sensor was positioned vertically, facing the source of illumination. To stabilize the reading, the lux meter was kept motionless for a brief period of time. It was assured that the sensor is not under shadow or illumination obstruction. Measurements were taken at several sites in order to detect uneven illumination or calculate the average illumination for reliable findings. In order to prevent measurement bias, it was made sure that nothing was reflecting or blocking light in the area of the sensor. The data captured by the device was saved in an Excel file for later processing once the measurements were finished (Mannan, 2020; Moerman, 2023).

2.2.1. Visualization of illumination

Visualization of illumination, as used in illumination design, is the process of illustrating the way light interacts with a space, usually with the aid of computer software such as Golden Software Surfer or other comparable tools (Kralikova et al., 2018). Designers can better grasp the distribution and illumination intensity as well as the effects of shadows and reflections on the surrounding space with the aid of these visualizations. Golden Software Surfer version 25.2.259 was used in this study to interpolate the illumination maps for each of the workspaces using the kriging approach. Applying the theory of random functions to spatially distributed data is known as geo-statistics. Geostatistical analysis was then applied to transform the point data into surface data (Chen et al., 2024; Choi et al., 2022; Shojaee Barjoee et al., 2023a). Kriging is an interpolation technique based on linear least squares estimate. With respect to the values of the function y at some other points $x^{(i)} \in$ IR for each $i \in \{1, ..., n\}$, the objective is to estimate the value of an unknown real function y at point x^*. The Kriging estimator is defined by:

$$\hat{y}(x^*) = \sum_{i=1}^{n} \lambda_i y(x^{(\mathrm{i})}) \quad (1)$$

where n is the number of surrounding observations; $x^{(i)}$ is a vecteur composed of the d values ($x_1^{(i)}$, ..., $x_d^{(i)}$) of the factors at point i, and λ_i is the weight corresponding to the observation $y\ (x^{(i)})$. To achieve minimal volatility in the estimator, the weights are estimated (Castric et al., 2012; Ustyugov et al., 2024).

2.3. Modeling setup

We employed a simulation work approach in this study project using DIAlux Evo (Králiková et al., 2022). Daylight is not taken into account in the simulation; only artificial illumination is. The calculations take into account only direct illumination. Prior to the program's implementation, the workspaces' length, width, and total height—as well as their average fruitful height, luminaire suspension height, and work plane—were recorded (**Table 1**). The second type of data in the program were surface characteristics of workplaces, such as the percentage of light reflection on the ceiling (ρ_{CC}), wall (ρ_W), and floor (ρ_{FC}) of the workplaces. DIALux mimics the actual behavior of illumination at a workplace by using reflection coefficients. This is essential for figuring out how light reflects off objects in the space since it influences the overall luminance and illumination distribution. The surface features, illumination setup, and physical dimensions of the ceramic industry workspaces are shown in **Table 2**. A light loss factor is a multiplier that is applied to an illuminative system's initial characteristics to forecast its future performance (maintained illuminance). The diminution of luminance as it leaves the illuminative source is measured by the light loss factor. This factor is established by taking into account multiple important factors that impact the overall effectiveness and performance of the system. The factors include: Luminaire Dirt Depreciation (LDD), Ballast Factor (BF), Room Surface Dirt Depreciation (RSDD), Temperature Factor, Maintenance Factor (MF), and Lamp Burnout Factor (LBO). To determine the overall

LLF utilized in luminance design, these variables are usually added together. The type of illuminated system, its position, and the maintenance plan are all configurable in DIALux, and these factors can affect the precise values. Once all the information needed for DIALux implementation was completed, the number of luminaires needed was determined. The number of luminaires needed was determined using a series of fundamental equations (Equations (1)–(5) in **Table 3**). The luminaires were then positioned throughout the workplaces such that they not only provided the necessary illumination but also had a beautiful and well-organized layout. In this context, particular attention was given to the lamp's dimensions, their spacing from one another, and their distance from the side walls. Note that any description given was limited to how an optimization scenario might be put into practice.

Table 1. Physical dimensions, surface characteristics and illuminative system of ceramic industry workplaces.

Workplaces	Dimensions			Reflection coefficient			Surface color			Light loss factor
	Length	Width	Total height	Floor	Wall	Ceiling	Floor	Wall	Ceiling	
	(m)			(%)			Dimensionless			(%)
Preparation of the ceramic body	54	50	14	10	35	50	Dark red	Pale yellow	Light gray	50
Press	60	30	14	10	35	50	Dark red	Pale yellow	Light gray	50
Glazing	40	20	10	10	35	50	Dark red	Pale yellow	Light gray	50
Glaze line	120	30	7	10	35	50	Dark red	Pale yellow	Light gray	50
Furnace	250	30	7	10	35	50	Dark red	Pale yellow	Light gray	50
Squaring	60	20	7	10	35	50	Dark red	Pale yellow	Light gray	50
Packing	75	20	7	10	35	50	Dark red	Pale yellow	Light gray	50

Table 2. Continues.

Workplace	Illuminative system								
	Luminaire	Fruitful height	Suspended height	Work plane	Layout pattern	Type of illumination	Color rendering index	Luminous efficacy	Luminance
		(m)			Dimensionless		Dimensionless	(Lm/w)	(Cd/m2)
Preparation of the ceramic body	Compact Fluorescent	4	9	1	Irregular	Semi-direct	85	50	5000
Press	Compact Fluorescent	4	9	1	Irregular	Semi-direct	85	50	5000
Glazing	Compact Fluorescent	4	4	1	Irregular	Semi-direct	85	50	5000
Glaze line	Compact Fluorescent	5	1	1	Irregular	Semi-direct	85	50	5000

Table 2. (*Continued*).

Workplace	Illuminative system								
	Luminaire	Fruitful height	Suspended height	Work plane	Layout pattern	Type of illumination	Color rendering index	Luminous efficacy	Luminance
		(m)			Dimensionless		Dimensionless	(Lm/w)	(Cd/m2)
Furnace	Compact Fluorescent	5	1	1	Irregular	Semi-direct	85	50	5000
Squaring	Compact Fluorescent	5	1	1	Irregular	Semi-direct	85	50	5000
Packing	Compact Fluorescent	5	1	1	Irregular	Semi-direct	85	50	5000

Table 3. Equations to calculate the number of required luminaires.

No	Metric	Definition	Equation	Description of the parameter
(1)	Illuminance intensity (*E*)	The area density of luminous flux in the illuminated place is called illuminance intensity; its unit is Lux.	$\mathrm{E} = \frac{\varphi}{\mathrm{A}}$	*Φ* is the luminous flux (lm); and A is the area (m^2)
(2)	Luminous efficacy (*η*)	The ratio of illuminance power (light current) to the electric power of the luminaire is called the luminous efficiency of that luminaire. An index of how well light is generated.	$\eta = \frac{\varphi}{\mathrm{P}}$	*Φ* is the luminous flux (lm); and P is the electric power of the luminaire (W).
(3)	Luminous flux (*φ*)	This metric is the amount of energy that a source radiates over visible wavelengths per unit of time (dQ/dt).	$\varphi = \frac{\mathrm{E} \times \mathrm{A}}{\mathrm{CU} \times \mathrm{LLF}}$	*E* is the illuminance intensity (lux); *A* is the area (m^2); and CU is the coefficient of utilization (dimensionless); LLF is loss of light factor (dimensionless).
(4)	Coefficient of utilization (CU)	The illuminance output of each luminaire is proportional to the amount of illuminance reflection from the ceiling, wall, and floor. Each luminaire has a special CU table, which includes the RCR value and the illuminance reflection percentages from the ceiling, wall, and floor.	$\mathrm{RCR} = \frac{5\mathrm{hr} \times (\mathrm{L} + \mathrm{W})}{\mathrm{L} \times \mathrm{W}}$	hr is the fruitful height (m); *W* is the width (m); and *L* is the length (m).
(5)	Number of luminaires required (*n*)	Determining the total number of luminaires required in the desired space.	$\mathrm{n} = \frac{\varphi}{\varphi_1}$	*Φ* is the luminous flux (lm); and φ_1 is the luminous flux of the selected luminaire (lm)

2.4. Design scenarios and optimization

The uniqueness of the workplaces has greatly impacted the illumination design, particularly the selection of luminaires. The luminaires must guarantee appropriate illuminance values and have the least negative effect on workers' night vision because this is an industrial setting. LED luminaires are recommended under these criteria as an alternative to more traditional options, such as compact fluorescent luminaires. The goal was to achieve uniform illumination throughout the workplace. To find the optimal illumination scenario with a consistent distribution of illumination and a level of 250 lux, sixteen different illumination scenarios were examined for each workplace. When it comes to response surface methodology (RSM), Design Expert is a potent software application that is utilized for both optimization scenario design and statistical analysis. In this study, the Design Expert program version 13.0.5.0 was used to design optimization scenarios of the illumination of the workplaces. In this regard, the Central Composite Design (CCD) was employed to clarify the effects of the factors in the illumination (Shojaee Barjoee et al., 2023b). To construct a second-order (quadratic) model for the response variable in RSM without requiring a complete three-level factorial experiment, CCDs are a popular test design. When analyzing the experimental data statistically, the CCD performs more accurately. The input factors for the optimization procedure were determined to be the light loss factor (A), height of suspension (B), number of luminaires (C), and luminous flux (D). The factors were coded with a central coefficient ($\alpha = 2$). In order to classify responses into a restricted number of categories or classes, the process of assigning numbers or other symbols to answers is known as coding. The illumination was predicted based on the two levels selected. The manipulated factors were varied on two levels: a high level, represented as (+1), and a low level, represented as (−1). The range of the selected factors is reported in **Table 4**. The LLF takes into consideration how ambient conditions, dirt buildup, and luminaire deterioration can all contribute to a decrease in illumination output over time. In order to save energy costs and maintain a safe, efficient, and well-lit ceramic industry, illumination optimization strategies must take the light loss factor into account. The secret to maintaining ideal illumination conditions over time is routine inspections and upkeep. The light loss factor in DIALux is a crucial factor for precisely estimating lighting needs and guaranteeing that the intended illumination levels are sustained over time. The value of this factor in DIALux varies from 0.5 to 0.80. Industrial settings with pollution are assigned a value of 0.5, while clean environments with comparatively good maintenance conditions are assigned a value of 0.8. A crucial component of illumination optimization is the height of suspended luminaires, which affects both the illumination's distribution and the illumination design's overall efficacy. The illumination intensity that reaches the work surface depends on one's distance from it. While higher luminaires may produce less intensity, lower luminaires typically offer higher illumination intensity. A proper height can help reduce shadows and dark areas by achieving homogeneous lighting across the space. To sum up, optimum suspension luminaire height entails striking a balance between the room's characteristics, safety requirements, aesthetic preferences, and illumination requirements. The study determined the luminaire suspension height based on the height of the workplace ceilings. **Table 4** displays the chosen values for this factor.

Table 4. Value of desired factors to optimize illuminance in workplaces.

Workplace	Light loss factor (*A*)	Height of suspension (*B*)	Number of luminaires (*C*)	Luminous flux (*D*)
	Dimensionless	Meter	−	Lumen
Preparation of the ceramic body	+1 (0.8)	+1 (9)	+1 (120)	+1 (10500)
	−1 (0.5)	−1 (6)	−1 (54)	−1 (6300)
Press	+1 (0.8)	+1 (9)	+1 (72)	+1 (10500)
	−1 (0.5)	−1 (6)	−1 (36)	−1 (6300)
Glazing	+1 (0.8)	+1 (6)	+1 (30)	+1 (10500)
	−1 (0.5)	−1 (4)	−1 (18)	−1 (6300)

Table 4. (*Continued*).

Workplace	Light loss factor (*A*)	Height of suspension (*B*)	Number of luminaires (*C*)	Luminous flux (*D*)
	Dimensionless	**Meter**	**−**	**Lumen**
Glaze line	+1 (0.8)	+1 (3)	+1 (143)	+1 (10500)
	−1 (0.5)	−1 (1)	−1 (80)	−1 (6300)
Furnace	+1 (0.8)	+1 (3)	+1 (240)	+1 (10500)
	−1 (0.5)	−1 (1)	−1 (147)	−1 (6300)
Squaring	+1 (0.8)	+1 (3)	+1 (48)	+1 (10500)
	−1 (0.5)	−1 (1)	−1 (18)	−1 (6300)
Packing	+1 (0.8)	+1 (3)	+1 (63)	+1 (10500)
	−1 (0.5)	−1 (1)	−1 (52)	−1 (6300)

An illumination design's ability to maximize illumination in any given space is greatly influenced by the quantity of luminaires employed. For activities requiring precision, a more uniform distribution of illumination can be achieved with a larger number of luminaires, thereby decreasing shadows and dark patches. The number of luminaires installed in the studied ceramic industry (−1) and the number of required luminaires estimated by manual calculations and DIALux software (+1) are presented in **Table 4**. Arranging luminaires to optimize lighting involves a strategic approach that considers the purpose of the space, the type of activities taking place, and the desired ambiance. **Table 5** shows the number of luminaires arranged horizontally and vertically.

Table 5. Scenario of the number of luminaires with horizontal and vertical arrangement in the workplaces.

Arrangement	Preparation of the ceramic body	Press	Glazing	Glaze line	Furnace	Squaring	Packing
Horizontal	12	9	6	13	18	8	9
Vertical	10	8	5	11	16	6	7
Total	120	72	30	143	288	48	63

An essential component of workplace illumination optimization is luminary flux, which is expressed in lumens. It directly influences visibility, comfort, and productivity. In order to ensure that tasks may be completed safely and effectively, adequate luminous flux is necessary. Higher luminous flux improves visibility for detailed tasks. Managers of the ceramic industry can customize illumination to meet the unique demands of workers by incorporating LED technology, which enables adjustable luminous flux through dimming capabilities or smart controls. In this study, LED luminaires with a power consumption of 100 W and a luminous flux of 10,500 lm were recommended to optimize workplace illumination. More features of the proposed technology are shown in **Figure 3**.

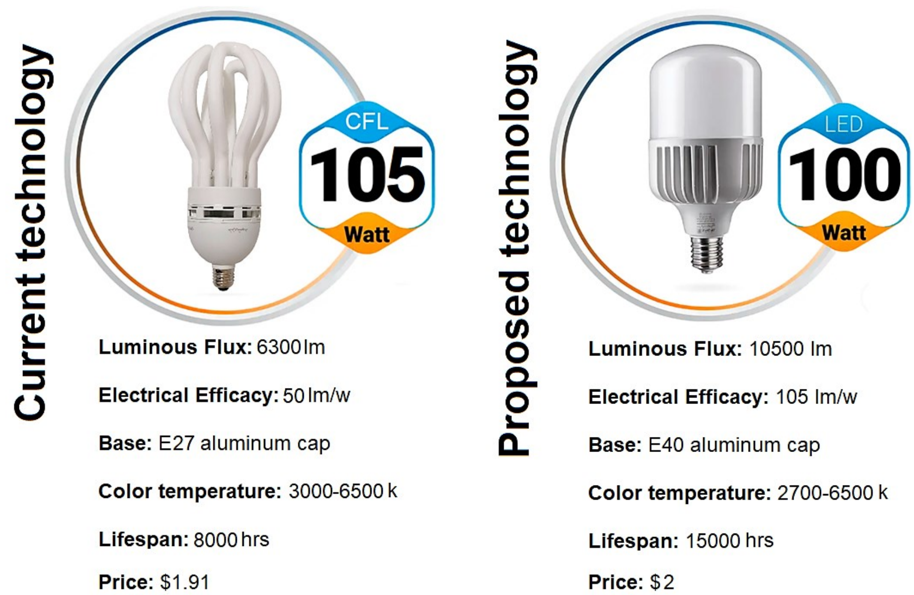


Figure 3. Comparison of illuminance parameters of current and proposed technology.

The DIALux software was carry out for each scenario in accordance with the particular settings of the factors. The output of the DIALux program was shown using five parameters: E_{min}, E_{max}, E_{av}, E_{min}/E_{av} and, E_{min}/E_{max}. The E_{min}/E_{ave} value was evaluated in order to determine which scenario was the best. Specifically, a study scenario is considered favorable if the E_{min}/E_{ave} value is close to 1.

2.5. Statistical analysis of scenarios

Planning, analyzing, conducting, and interpreting modeled data with great care are all necessary for statistical analysis of CCD scenarios in Design Expert. By taking these actions, we can efficiently use CCD to investigate the connections between responses and factors, which will result in the optimization of the illumination parameters. In this method, the relationship between factors and illumination is shown using a quadratic equation with interaction terms. An analysis of variance (ANOVA) was used to determine the best-fit model from the obtained illumination for each scenario in order to assess the degree of desirability of the optimized illumination of the workspaces (Roy and Satvaya, 2022). Then, the individual and interactive effects of the factors were investigated using the quadratic model. The illumination desirability score obtained for each of the workplaces was examined to evaluate the accuracy of the results. In all statistical analyses, p values less than 0.05 were considered significant.

3. Results

3.1. Analysis of experimental results

Figure 4 displays the illumination measurement findings for each ceramic industry workplace as a heat map. This map is based on the frequency of illumination measurements in each measurement range. The workspaces in packaging and press had the greatest and lowest illumination values, respectively. Between 2 and 1506 lux was the measured range of illumination in the ceramics sector. The workplaces were grouped in the following descending order based on average illumination values: packing > glaze line > furnace > squaring > preparation of the ceramic body > glazing.

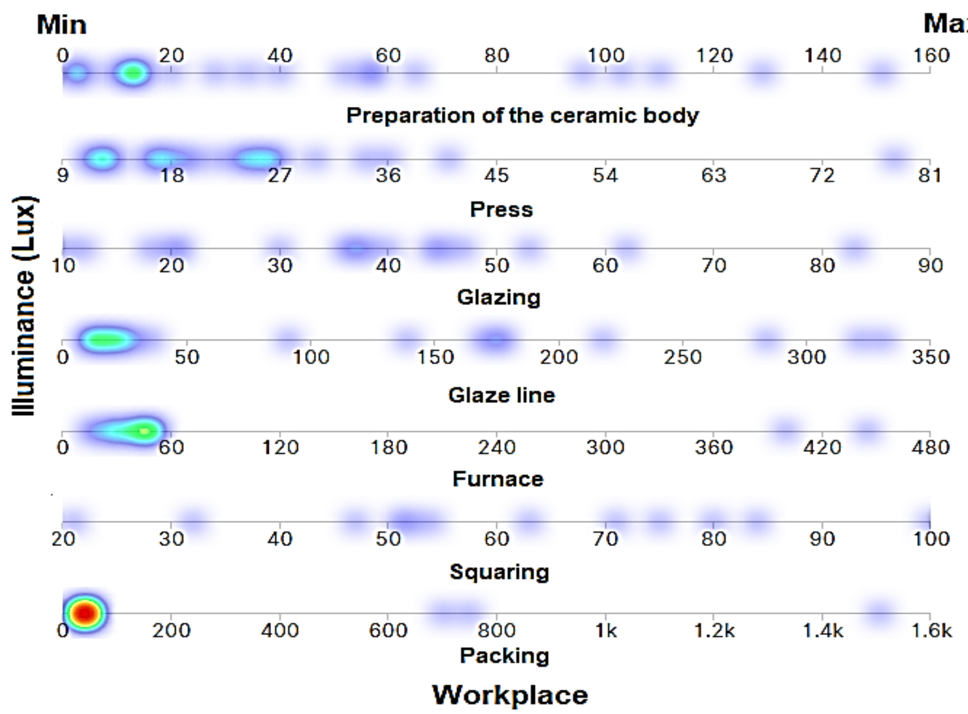


Figure 4. Heat map of illuminance in workplaces.

The illumination data in the investigated ceramic sector workplaces did not have a normal distribution, according to the Kolmogorov-Smirnov (k-s) test results for workplaces such as press, glaze line, furnace, and packing (*p*-value > 0.05). This suggests that the illumination is not distributed uniformly throughout the workspaces in these workplaces (**Table 6**).

Table 6. Results of Kolmogorov Smirnov test.

Workplace		**Preparation of the ceramic body**	**Press**	**Glazing**	**Glaze line**	**Furnace**	**Squaring**	**Packing**
N		22	23	16	19	14	12	17
Normal Parameters[a,b]	Mean	46.59	24.39	37.25	110.89	91.92	60.83	207.82
	Std. Deviation	44.69	14.20	19.19	113.10	140.77	22.51	404.04
Most Extreme Differences	Absolute	0.17	0.210	0.11	0.27	0.47	0.11	0.47
	Positive	0.17	0.21	0.11	0.27	0.47	0.11	0.47
	Negative	−0.15	−0.17	−0.09	−0.18	−0.29	−0.10	−0.32
Test Statistic		0.17	0.21	0.11	0.27	0.47	0.11	0.47
Asymp. Sig. (2-tailed)		0.06c	0.01c	0.20[c, d]	0.00c	0.00c	0.20[c, d]	0.00[c]

Note: a. Test distribution is Normal; b. Calculated from data; c. Lilliefors Significance Correction; d. This is a lower bound of the true significance.

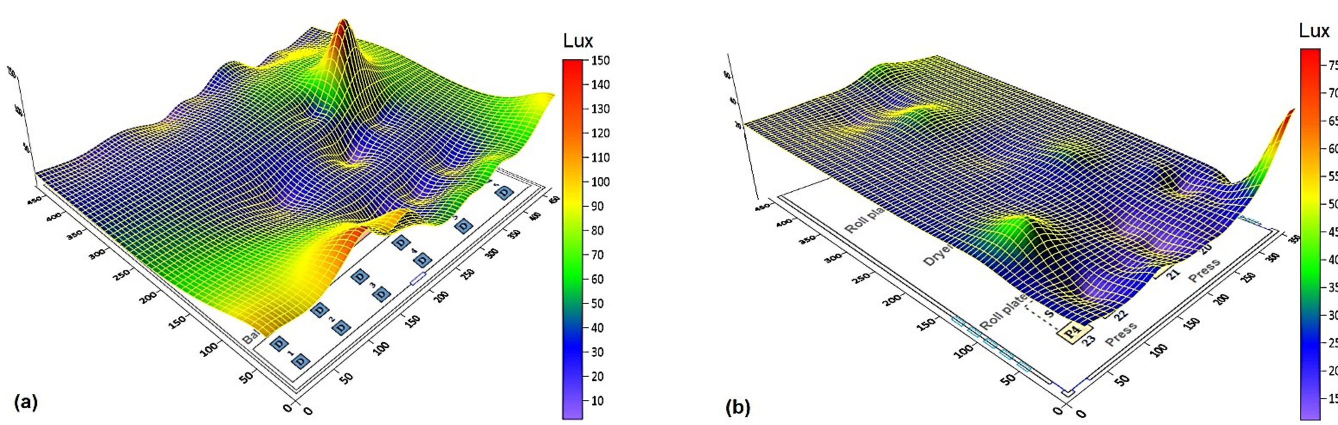
Depending on the nature of the task being done, different illumination requirements apply in industrial settings. A standard illumination of 250 lux was established on average based on the actions of workers in all workplaces. The measured data was compared to the standard workplace illumination values (250 Lux) using the *t*-test. The findings demonstrated that the measured illumination data and the standard values differ significantly (p-value < 0.05) for all workplaces except packing (**Table 7**).

Table 7. Comparison of measured illuminance values with standard 250 lux using *t*-test.

Workplace	Test Value = 250					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Preparation of the ceramic body	−21.34	21	0.00	−203.40	−223.22	−183.59
Press	−76.15	22	0.000	−225.60	−231.75	−219.46
Glazing	−44.32	15	0.000	−212.75	−222.98	−202.51
Glaze line	−5.36	18	0.000	−139.10	−193.61	−84.59
Furnace	−4.20	13	0.001	−158.07	−239.35	−76.78
Squaring	−29.10	11	0.000	−189.16	−203.47	−174.85
Packing	−0.43	16	0.673	−42.17	−249.91	165.56

3.2. Visualization of illumination

Illuminance visualization is one of the best methods for predicting the distribution of illumination in a workplace so that illuminative systems may be developed more efficiently. The illumination in this investigation was visualized using the kriging approach. The outcomes of this visualization are shown in **Figure 5**. It is clear that the illumination dispersion was not interpolated uniformly across different work environments. The interpolated illuminance is quite low in several places. These results, however, show that there is no defined standard or guideline followed in the construction of the illuminative systems at workplaces.



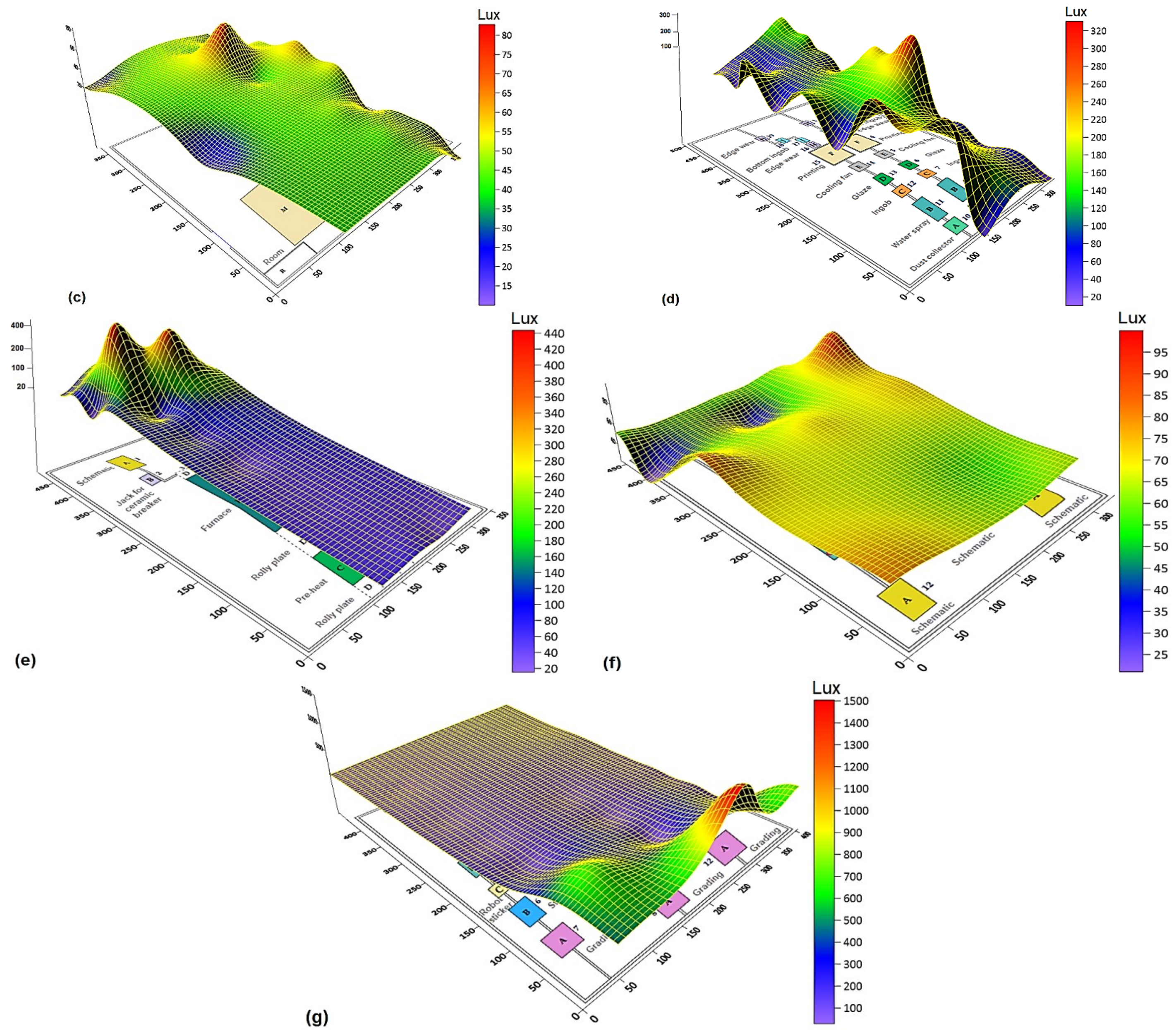


Figure 5. 3D measured luminance maps of the preparation of the ceramic. **(a)** body; **(b)** press; **(c)** glazing; **(d)** glaze line; **(e)** furnace; **(f)** squaring; **(g)** packing.

3.3. Configure scenarios

Using the CCD technique, 16 scenarios were chosen at random for each workplace to serve as the experimental design. **Tables A1–A7** in the Appendix display the outcomes of the 16 scenarios that were modeled in the DIALux program for each workplace. A set of five parameters—Eave, Emin, Emax, Emin/Emax, and Emin/Eave—were used to determine the optimal illumination conditions. These parameters represented the average, minimum, and maximum illumination levels as well as the ratios of minimum to maximum and minimum to average illuminance. The illuminative system's ideal design is indicated by Emin/Eave, which is the most crucial parameter for determining which scenario is most appropriate. A design that maximizes illumination conditions is more advantageous when the Emin/Eave index value is near one. **Table 8** displays the outcomes of the optimal scenarios for maximizing illumination conditions in each workplace.

Table 8. The best scenario selected for illuminance optimization in the ceramic industry.

Workplace	Light loss factor	Height suspended of luminaire	Number of luminaires	Luminous flux of luminaire	Eave	Emin	Emax	Emin/Emax	Emin/Eave
	Dimensionless	m	−	lm/w	Lux				Dimensionless
Preparation of the ceramic body	+1 (0.8)	−1 (6)	+1 (120)	+1 (10500)	315	136	378	0.36	0.43
Press	+1 (0.8)	−1 (6)	+1 (72)	+1 (10500)	267	117	325	0.36	0.44
Glazing	+1 (0.8)	−1 (4)	+1 (30)	+1 (10500)	250	108	310	0.35	0.43
Glaze line	+1 (0.8)	−1 (1)	+1 (143)	+1 (10500)	294	113	391	0.29	0.38
Furnace	+1 (0.8)	−1 (1)	+1 (288)	+1 (10500)	286	90	499	0.18	0.31
Squaring	+1 (0.8)	−1 (1)	+1 (48)	+1 (10500)	272	115	346	0.33	0.42
Packing	+1 (0.8)	−1 (1)	+1 (63)	+1 (10500)	288	123	378	0.33	0.43

3.4. Statistical analysis of scenarios

The ANOVA results of the scenarios for each of the workplaces are presented in **Tables A8–A14** in the supplementary information file. It was predicted that the four independent factors—luminous flux, number of luminaires, height suspended of luminaire, and light loss factor—would have a substantial impact on illumination values (p-value < 0.01). There were significant effects from the way that different independent factors interacted to affect the illumination in each workspace (p-value < 0.01). It was predicted that effects of the combined factors of light loss factor with number of luminaires, light loss factor with luminous flux, and number of luminaires with luminous flux would have a significant effect on illumination in workplaces such as the ceramic body preparation, pressing, glazing, glazing line, and furnace (p-value < 0.01). The impact of four factors together—the number of luminaires with luminous flux, the suspended height of luminaires with luminous flux, and the light loss factor with the number of luminaires—was predicted to be significant (p-value < 0.01) in the squaring workplace. In the packaging workplace, the result of the interaction of the following factors on lighting was predicted as follows: light loss factor with height suspended of luminaire, light loss factor with number of luminaires, light loss factor with luminous flux, height suspended of luminaire with luminous flux, and number of luminaires with luminous flux. In **Table 9**, the fitted models for each workplace are presented.

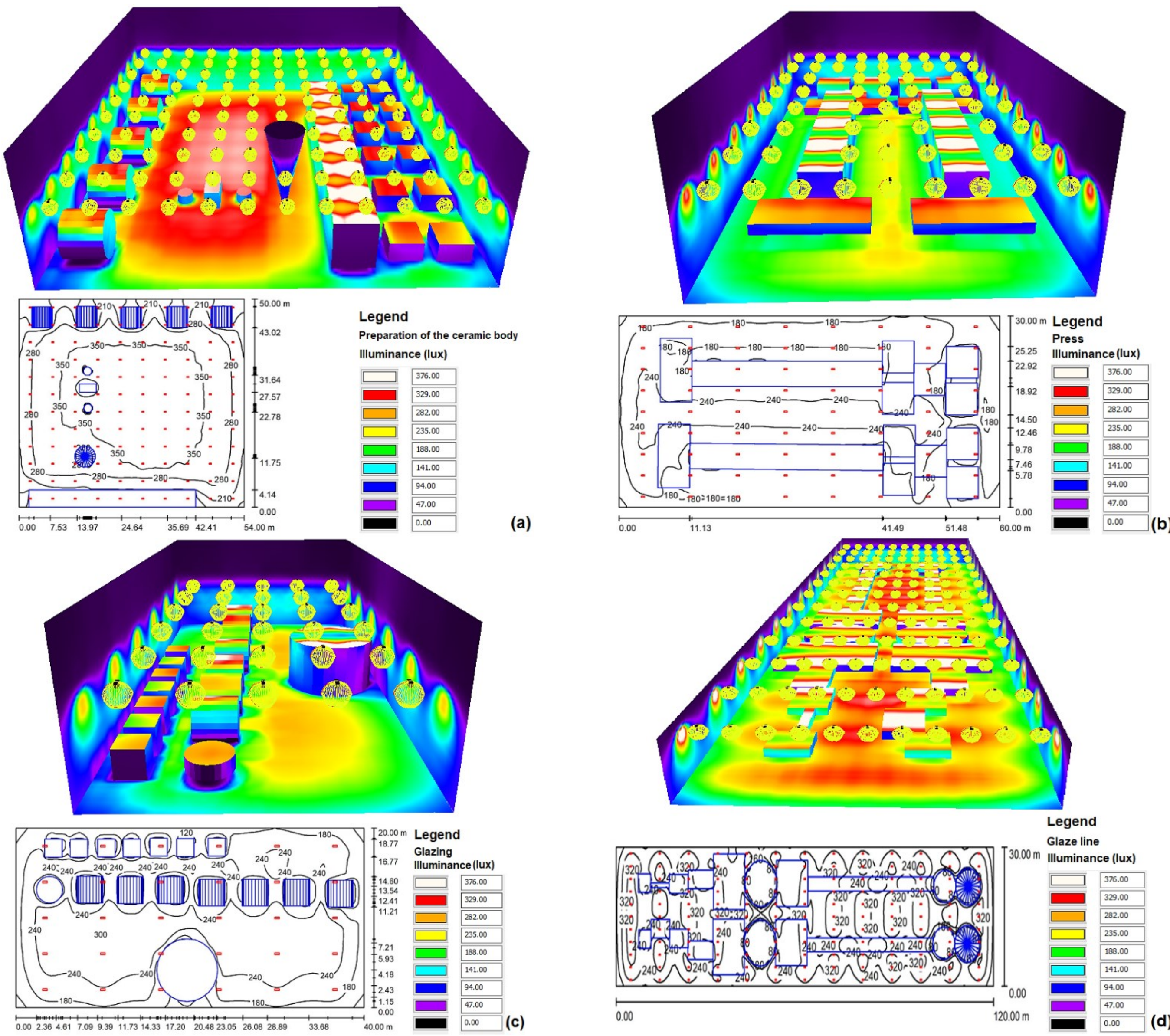
Table 9. Fitted models to predict illumination optimization.

Workplace	Source	Std. Dev.	*R*-Squared	Adjusted *R*-Squared	Predicted *R*-Squared	Pre SS	Result
Preparation of the ceramic body	Linear	26.89	0.9261	0.8992	0.8437	16,827.64	
	2FI	6.12	0.9983	0.9948	0.9822	1918.08	Suggested
	Cubic	0.75	1.0000	0.9999	0.9987	144.00	Aliased
Press	Linear	21.69	0.9305	0.9053	0.8530	10,952.33	
	2FI	4.96	0.9984	0.9951	0.9831	1257.60	Suggested
	Cubic	0.25	1.0000	1.0000	0.9998	16.00	Aliased
Glazing	Linear	17.20	0.9434	0.9228	0.8802	6881.85	
	2FI	3.77	0.9988	0.9963	0.9873	727.04	Suggested
	Cubic	0.50	1.0000	0.9999	0.9989	64.00	Aliased
Glaze line	Linear	20.89	0.9392	0.9171	0.8714	10,153.79	
	2FI	4.60	0.9987	0.9960	0.9863	1082.88	Suggested
	Cubic	0.50	1.0000	1.0000	0.9992	64.00	Aliased
Furnace	Linear	21.42	0.9352	0.9116	0.8629	10,675.17	
	2FI	4.70	0.9986	0.9958	0.9855	1129.60	Suggested
	Cubic	0.75	1.0000	0.9999	0.9982	144.00	Aliased
Squaring	Linear	25.76	0.9216	0.8931	0.8342	15,442.91	
	2FI	5.72	0.9982	0.9947	0.9820	1672.32	Suggested
	Cubic	4.75	0.9998	0.9964	0.9380	5776.00	Aliased
Packing	Linear	14.85	0.9647	0.9519	0.9254	5132.03	
	2FI	2.23	0.9996	0.9989	0.9963	254.08	Suggested
	Cubic	0.75	1.0000	0.9999	0.9979	144.00	Aliased

Figure 6 displays two- and three-dimensional maps with simulated illumination for every workplace in the DIALux software. On the work plane of the workplaces, there is more than 250 lux of illumination. The following is a description of the illumination in each workspace:

Ceramic body preparation workplace: This workplace has two hydraulic motors, a spray, a motor, a soil silo, five ball millings, and a vibrating sieve among its most crucial pieces of equipment. The workflow of workers with equipment in this workplace is described as follows:

Ball milling: It involves the use of a rotating cylindrical container filled with balls (usually made of steel, ceramic, or other materials) and the material to be milled. As the container rotates, the balls collide with the material, causing it to break down into smaller particles. Ball millings daily settings should be checked by workers, which will include the following: 1) Installing a solid base to minimize machine vibration; 2) Ensuring that the mill is properly aligned for optimum performance; 3) Adjusting the electrical connections according to the manufacturer's specifications and ensuring compliance with safety measures; 4) Ensuring that raw materials have adequate moisture levels to prevent clumping; 5) Determining the optimal ratio of pellets to raw materials for effective grinding; 6) If necessary, additives should be added that can improve the milling process or improve the properties of the final product; 7) Adjusting the speed and duration of grinding based on the characteristics of the material and the desired fineness; 8) Continuous monitoring to prevent overheating and ensure consistent results, grinding process; 9) The particle size and distribution of the milled material should be tested regularly to ensure compliance with specifications; 10) The grinding process should be modified based on quality control feedback.



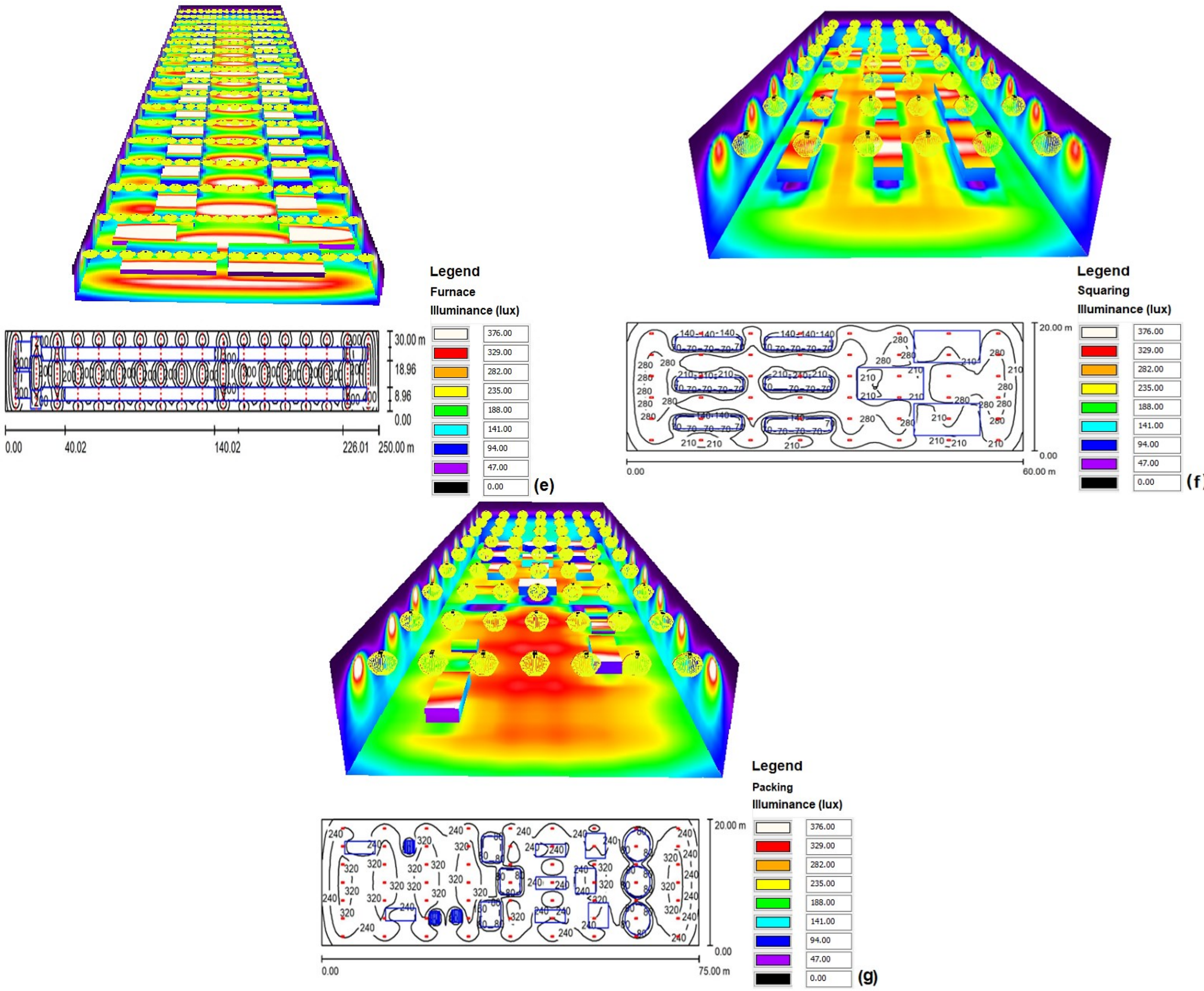


Figure 6. Two-dimensional and three-dimensional map of optimized illuminance distribution in: **(a)** the preparation of the ceramic body; **(b)** press; **(c)** glazing; **(d)** glaze line; **(e)** furnace; **(f)** squaring; **(g)** packing.

Hydraulic motors: In the ceramic industry, hydraulic motors play a key role in powering spray. Hydraulic motors, especially when high torque and variable speeds are required provide the mechanical power needed to operate spray nozzles.

Spray: The purpose of sprays is to dry the slurry and create granules with a particular granulation and moisture content. Daily adjustments of the spray should be checked by workers to see whether the bearing and sealing parts are adjusted, the condition of the lubricating oil of each mechanical part, and whether each slurry pipe valve is in the required position or needs to be adjusted. The slurry concentration in the slurry mixing barrel should be checked; if there is a problem, it should be removed in time. When the discharge valve temperature reaches the set temperature (usually about 130 ℃), the material pump and dust removal system should be started. When the pump pressure reached 2 MPa, he turned on the spray and started granulation. Following equipment use, it is important to promptly check the atomization state and the material pump's functioning; if the spray is obstructed, the nozzle needs to be cleaned or replaced. After the normal operation of the equipment, the materials should also be collected on time, and the performance of the system should be checked on time. The process parameters should be recorded, and attention should be paid to the completion of the oscillating filter screen. The spray device should be turned off when granulation is complete. After that, workers should unscrew the nozzle and clean it. The fan and extractor can be turned off when the inlet temperature falls below 100 °C. The final steps in this workplace include placing the remaining materials in the drying tower and dust collector, closing the dust collector, shutting off the main power supply, and concluding production. The material pump, feed fan, and equipment should all be turned off right away in an emergency. All the tasks mentioned to manage this workplace require illumination up to 250 lux. As can be seen, the illumination in this workplace is optimized within 250 lux (**Figure 6a**). A total of 120 luminaires, placed in 10 columns and 12 horizontals spaced 4.5 m apart from one another, were found to be necessary to maximize the illumination at this workspace. It was calculated that the illuminative system was roughly 2.5 m away from the wall's edges. This optimization led to an increase in illumination up to 329 lux around spray and ball millings, which require precise adjustments by workers. When installing this illuminative system in the ceramic body preparation workplace, the normalized power density standard in $W/m^2/100$ lux must be followed. In this way, the specific connected load (luminaire output) for this optimization is expected to be 4.44 W/m^2. Before optimization, the value of this parameter was 2.10 W/m^2. It is necessary to divide the total energy used for illumination by the floor area and by a hundredth of the area's illumination. In this way, the value of this adjusted parameter before and after optimization will be equal to 3.59 and 1.47 $W/m^2/100$ lux, respectively.

Press workplace: In this workplace, the granules produced by the spray machine are shaped by the press machine to reach the desired design. The equipment installed in this workplace includes two dryers and four presses. In the front areas of the sprays and dryers, there are roller plates that guide the granules towards the dryers and sprays. The tasks performed by the employees at this business decide how much lighting is needed. The following are among the responsibilities of the employees in this workplace: 1) correct setting of dryer parameters; 2) adjusting the speed of roller dryers; 3) adjusting the drying time depending on the material and moisture content; 4) unloading or loading the ceramic body; 5) ensuring that the ceramic body is properly placed under the press plate to achieve uniform drying; 7) check for signs of overheating, such as discoloration or burning of the ceramic body; 8) ensuring dryer ventilation and cooling systems are working to prevent overheating or fire hazards; 9) regular cleaning of the dryer to prevent accumulation of dust, lint, or debris that can affect performance and safety. The illumination level of 250 lux was established as the standard value for employees' well-being based on the above-described tasks. It was found that 72 luminaires were needed. The luminaire arrangements in this workplace were judged to be 9 columns spaced roughly 6 meters apart from one another and 8 horizontal arrangements spaced roughly 6 meters apart. The illumination is optimized to 329 lux in the roller plate sections and 376 lux around the presses and dryers, where the majority of the personnel are working, as shown in **Figure 6b**. The specific connected load (luminaire output) for this optimization is expected to be 4.00 W/m^2 = 2.05 W/m^2/100 lux.

Glazing: This workspace has seven ball millings, a scale, a glazing reservoir, and a control room. Glazing materials are the priciest raw materials used in the ceramics industry. This is the stage of the ceramic production process where carelessness will result in a low-quality finished product. The primary tasks performed by the employees in this workplace are to accurately calculate loading batches, weigh and prepare the glaze ingredients, continuously monitor the glaze's properties such as resistance, density, and viscosity, ensure that the loaded formula is accurate, clean the inside of the ball mills and their balls, and write a breakdown report that is sent to the industry's technical unit. Given that the activities assigned to the employees in this workplace do not necessitate a high degree of precision, it is adequate to set the appropriate illumination to 250 lux. The average illumination in this workplace is currently measured at 37.5 lux; thus, six horizontal luminaires positioned six meters apart and five columns of luminaires spaced three meters apart will provide the optimized illumination. **Figure 6c** displays the optimization's outcome. At the level of the ball mills and the glazing reservoir, the optimum illumination is up to 376 lux; at the scale's level, 282 lux, the ball mill's valve is optimized from 235 to 282 lux. The specific connected load (luminaire output) for this optimization is expected to be 3.75 W/m^2 = 1.73 W/m^2/100 lux.

Glaze line: This workplace consists of two complex and interconnected systems for glazing ceramic bodies. This complex system is made up of a number of parts, including grinding the side of the ceramic body, printing, glazing, underglaze (engob), water spray, dust fan, and bottom engob. Among the duties of workers that require lighting, the following can be mentioned: checking the weight of water, viscosity, and density of the glaze; checking the defects in the glaze line; checking the suitability of abrasives in such a way that they do not cause defects of the side of the ceramic; and examination of the glue cabin. In the glue cabin, an excess of glue on the ceramic will cause it to adhere under the stencil; an insufficient amount of glue will result in sluggish printing. Employee work in this environment is becoming increasingly precise, necessitating up to 300 lux of illumination. The current level of illumination in this workplace is 110.89 lux. A total of 143 luminaires should be arranged in 13 horizontals with a spacing of 9 meters and 11 columns with a distance of 2 m from one another in order to provide ideal illumination levels up to 300 lux. The result of this optimization is shown in **Figure 6d**. As can be seen, the illumination level up to 376 lux includes important parts of the glazing line that require more attention and supervision by the workers. The specific connected load (luminaire output) for this optimization is expected to be 3.97 W/m^2 = 1.68 W/m^2/100 lux.

Furnace workplace: There are two lines in this workplace. Roll plates, furnace, preheater, ceramic breaker jack, and schematic are the components that make up each line. The responsibilities that employees are required to complete are delineated in the two sections of the furnace entrance and exit. The workers in charge of product quality control are stationed at the furnace's entrance; their duties include ensuring that the ceramics are not damaged during production and inspecting them for flaws, including missing or cracked glaze, fissures, and broken corners. The workers' responsibilities in the furnace's exit section include monitoring, measuring the thickness, length, and width of the product exiting the oven with the help of calipers, and recording flaws, as well as assessing the strength of baking and absorbing water. The illumination required for the optimal performance of workers in some parts of these units has been determined to be up to 250 lux. Thus, it was found that 288 luminaires, arranged in 16 column and 18 horizontal configurations, were required to maximize working conditions. The optimization results showed that the illumination increased up to 376 lux (**Figure 6e**). The specific connected load (luminaire output) for this optimization is expected to be 3.84 W/m^2 = 1.54 W/m^2/100 lux.

Squaring workplace: Three lines are present in this workspace to calibrate the size of ceramic bodies as they depart the furnace before packaging. In order to guarantee that ceramic is precisely cut, squared, and completed in accordance with the necessary requirements, workers in squaring workplaces in the ceramics sector must perform a variety of activities. Workers modify the squaring equipment according to the necessary dimensions. This includes adjusting wheels or cutting blades to the appropriate size and making sure they are correctly aligned. They may need to enter the necessary dimensions or parameters onto the control system because some squaring equipment may use automated or CNC technologies. They make sure the cutting and grinding operation is steady and seamless, modifying the equipment as needed to prevent flaws. They measure the ceramics after they have been squared to make sure they match the necessary requirements for size and squareness. They check the surfaces and edges for flaws that could compromise the ceramic's utility or appearance, such as chips or cracks. They are in charge of cleaning the squaring machine, doing routine maintenance (such as changing out worn-out wheels or blades), and making sure that every component is operating as it should. The illumination required for this workplace was determined to be 250 lux. To increase the illumination in this workplace to the optimal level, it is necessary to increase the number of luminaires from 18 to 48. The lamps should be arranged in 8 horizontals with a distance of 6 m and 8 columns with a distance of 2 m from each other. In this way, the illumination in this workplace increased to 376 lux, which mainly dispersed these contours in the important work plane (**Figure 6f**). The specific connected load (luminaire output) for this optimization is expected to be 4.00 W/m^2 = 1.84 W/m^2/100 lux.

Packing workplace: To finish the ceramic production stage, a number of procedures are followed at the packing workplace. These processes include palletizing, grading, stacking, cartooning, shearing, and finally packing. The aforementioned steps must be monitored by the packaging workplace's workers. Additionally, they make certain that ceramic goods are packaged effectively and properly for transportation and storage. Their main responsibilities include packing shipments, wrapping fragile goods, and getting goods ready for distribution. Workers write critical information on each box, including the product's specifications, the destination, its weight, and handling guidelines. To keep track of what has been packed and make sure the right things are transported, they record product codes, batch numbers, and order data. Nonetheless, it is advised that this workplace have 300 lux of illumination. It is not ideal that the average illumination in this workspace is currently assessed at 207.82 lux. According to the outcomes of lighting optimization, 63 luminaires are required to enhance illumination in packaging-related workplaces. The illumination arrangement in this workplace is planned so that 7 luminaires are stacked in a column with a spacing of 2 m between each luminaire and 9 luminaires positioned horizontally with a spacing of 8 m between each luminaire. The outcome of this optimization is an increase in workplace lighting of up to 376 lux, which is dispersed over several areas like grading, palletizing, cartooning, and stacking (**Figure 6g**). The specific connected load (luminaire output) for this optimization is expected to be 4.20 W/m^2 = 1.72 W/m^2/100 lux.

3.5. Optimized illuminance desirability

Figure 7 compares the illumination values that were measured, simulated, and optimized. As can be observed, in the ceramic body preparation, pressing, and glazing workspaces, the measured illumination values are lower than the simulated illumination values. This is likely because several luminaires were off during the illumination measurement. The measured illumination in areas like packing, glazing lines, furnaces, and squaring was higher than the simulated illumination. This was most likely caused by a small number of luminaires—likely LEDs—that were not taken into account during the modeling process. Nevertheless, following optimization, the illumination levels rose to 250 lux, demonstrating how well the simulation approach worked to enhance the illumination conditions for employees in the ceramics industry. Because the measured and optimized illumination conditions differ significantly, the impact of the illumination optimization plan's application in the press workspace is more apparent.

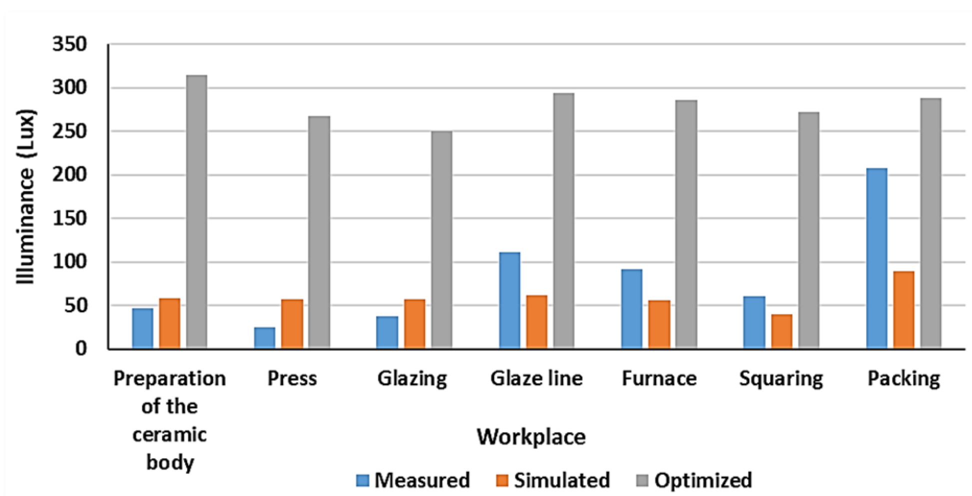
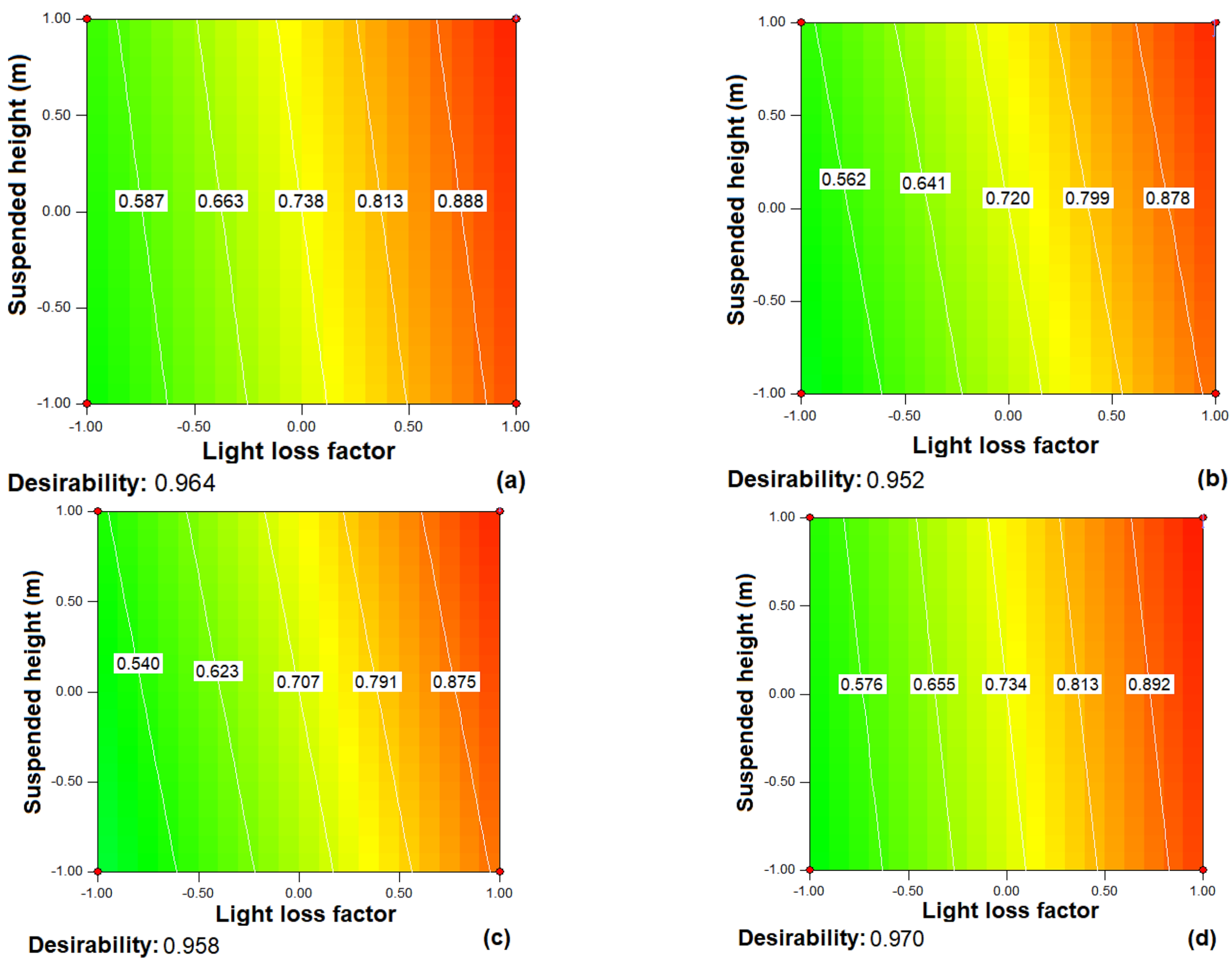


Figure 7. The average values for measured, simulated, and optimized illumination in the workplaces.

The Design-Expert software utilizes the "desirability function" to determine the optimal balance between various illuminance parameters, including light loss factor, height of suspension, number of luminaires, and luminous flux, in order to determine the degree of desirability for optimized illumination. In this way, the software many responses into a single value using the desirability function. Every response possesses a unique desirability function, which is then combined to determine the total desirability. For response that need to be maximized (illumination), the desirability function increases as the response value moves towards the upper end of the target range. The output of the desirability function is shown as a plot. Desirability plot show how factor changes affect the overall desirability score. In this study, the desirability degree of illuminance for each workplace was evaluated. **Figure 8** displays the findings of the illumination desirability degree determined for each workplace. For every workplace, the optimal illumination desirability degree was attained to a satisfactory degree. Desirability has a range of values from 0 to 1, where 1 denotes total desirability and 0 complete undesirability. For every workplace, the desirability degree score was greater than 0.9. The two primary factors influencing the illumination of every workplace were the height of suspension and the light loss factor.



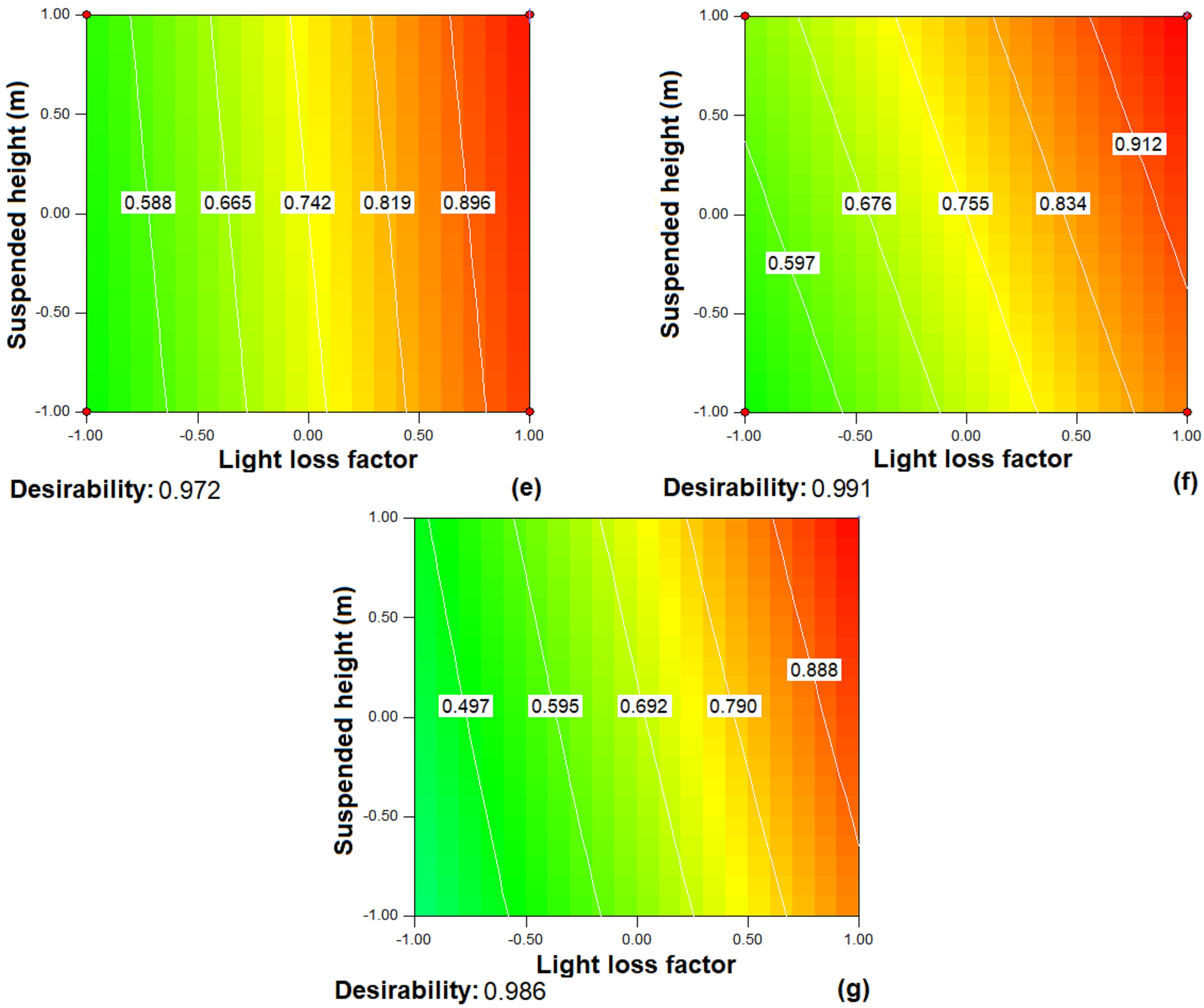


Figure 8. Desirable degree of illumination for: **(a)** the ceramic body preparation body; **(b)** press; **(c)** glazing; **(d)** glaze line; **(e)** furnace; **(f)** squaring; **(g)** packing.

4. Discussion

Green jobs are becoming more and more prevalent as a result of the demand for optimized and energy-efficient illumination, especially in the fields of energy auditing, illumination design, and installing sustainable solutions. This research provides a feasible design proposal and reference for improving an industrial lighting system. The themes covered in this paper are another step in extending the field of application for numerical experimental design tools. Governments typically utilize this as a springboard for more expansive economic plans that emphasize green businesses and innovation. Although these suites, like numerical experimental design, are extensively utilized in numerous industrial and research domains, their applicability as instruments for illumination design is limited. The primary causes are because they are not expressly designed for illumination, and occasionally the documentation contains incomplete or poorly thought-out information about illumination design. From a methodology perspective, the integration of DIALux lighting software with the numerical experimental design software Design-Expert is a good way to monitor and measure illumination in workplaces. DIALux is a great tool for illumination simulation and can assist designers in knowing the situation prior to design implementation. Additionally, the Designer-Expert software can help designers gain a deeper understanding of the factors that affect how illumination is distributed throughout various workspaces. The integration of both software tools can improve the design and management of workplace illumination. In this study for illumination improvement, 16 scenarios were designed using a numerical experimental design. In this study, based on the major factors influencing the ceramic industry illumination, the illumination requirements in different areas were analyzed. The results showed that a situation where the luminaire's height was less than its current height would be excellent. While the three factors of light loss factor, number of luminaires, and luminous flux had the highest value. The light loss factor has secondary effects, such as affecting initial cost and energy use, but it is also utilized to assist illuminative systems in meeting quantitative design goals over the course of the installation. The importance of this factor in illumination design and optimization has been mentioned in some studies. A study into LED light loss factor was carried out by Royer et al. They suggested values of 0.7 for this factor to improve illumination (Royer, 2014). The Bertin et al. study demonstrated how the light loss factor affected the luminaire life cycle assessment (LCA) and demonstrated that it needed to be considered in future evaluations (Bertin et al., 2019). Any light loss factor value that is taken into consideration, though, should be compatible with different illumination source technologies and allow for meaningful performance comparisons so that specifiers can identify goods that depreciate less over time. This can lead to improved aesthetic settings and significant energy savings. The luminous flux degradation of luminaires causes a gradual decline in light levels in the ceramic industry's illuminative system. If appropriate maintenance is not performed, this degradation could result in visual discomfort for the workers. Luminous flux deterioration was disregarded in the preceding illumination optimization problems. On the other hand, insufficient illumination has an impact on elements of human well-being like mood or degree of exhaustion. Even though they are frequently unaware of it, workers who experience illumination shortages on a regular basis may experience eye tiredness and functional difficulties. The primary benefit of the lighting optimization scheme developed in this study is that it keeps an eye on the degradation of luminous flux and maintains the illumination level requirements of workers at a consistent level. In this study, the parameter's value of 10,500 lumens was taken into consideration to enhance illumination conditions in the ceramic industry. To improve illumination, this parameter has, however, been given varied values in another research. For example, in a study by Ye et al. (2020), the luminous flux value of up to 11,665 lumens is considered to improve the illumination conditions. In the study of Leśko et al., the value of this parameter was determined up to 20,000 lumens (Leśko et al., 2020). For industrial sectors such as the ceramic sector, it is imperative to achieve effective illumination solutions that improve safety, comfort, and visibility by carefully balancing the number of luminaires and their hanging height. To provide proper lighting while reducing energy consumption and glare, a precise balance must be achieved, which will ultimately result in increased productivity and a safer workplace. To maintain ideal illumination conditions, evaluations and modifications must be made on a regular basis depending on particular requirements and jobs. The study's findings demonstrated the importance of these two parameters' influence on workplace illumination.

Several political and socioeconomic issues, such as corporate responsibility, environmental regulations, and worker rights, are frequently connected to workplace illumination optimization. In the ceramics industry, illumination optimization can have a number of important ramifications that affect production, quality, and overall efficiency. Below are some key outcomes:

Political outcomes:

Inadequate illumination in the ceramics sector has the potential to sustain social injustices, and initiatives to rectify this might be included in political discussions over social justice. Improving workplace illumination has been associated with a decrease in stress, weariness, and eye strain in employees. Politically, it is related to worker rights, particularly when talking about secure and healthy work environments. Regulations mandating improved illumination in workplaces as part of occupational health and safety standards may be pushed by advocates for workers. In certain instances, ceramic industries frequently have illumination conditions that are not ideal. Political debates against the unfair labor practices in the ceramic industries may surface, with the goal of establishing norms that help all workers, regardless of their line of employment. Sustainability practices in the ceramic industry, which are impacted by political incentives as well as public opinion, include illumination optimization. Lawmakers may propose regulations governing workplace illumination, including requirements for energy efficiency, color temperature, and illumination. Adherence to these guidelines may give rise to political controversy, particularly if businesses contend that these rules drive up expenses (Veitch, 2006).

Environmental outcomes:

Overall, optimizing illumination in the ceramic industry not only enhances operational efficiency but also contributes significantly to environmental sustainability. The ceramic sector can take significant steps toward a more sustainable future by cutting waste, emissions, and energy use while enhancing labor conditions and product quality. Proposed illumination solutions in the ceramic industry that are energy-efficient, like LED illumination, lower carbon footprints and are in line with political movements that support environmental sustainability. The lower energy of the LEDs used in this study is in line with sustainability objectives since it has a lessening effect on the environment. LEDs are harmful substance-free, safer for the environment, and easier to dispose of than fluorescent luminaires, which contain mercury (Wang et al., 2022).

Economic outcomes:

Energy savings from optimized workplace illumination can reduce operating expenses, although it can need an initial outlay of funds. Energy-efficient illumination usually lasts longer, which lowers the frequency of repairs and maintenance expenses. Better illumination can help reduce the number of defective ceramics, which will save money on labor and materials through improved quality control. In this study, LED technology was applied to enhance working illumination in the ceramics sector. LED illumination is a popular option for ceramic industry illumination because it has various advantages over fluorescent illumination. In this study, LED luminaires usually have a substantially longer lifespan than fluorescent ones—typically 15,000 hours versus 8000 hours for fluorescents. Lower maintenance expenses and fewer replacements result from this. LEDs are perfect for the ceramic sector since they are constructed of solid materials instead of glass, which makes them more durable and break-resistant. Compared to fluorescent luminaires, which can get fairly hot when operating, LEDs produce very little heat. This may result in lower cooling expenses for interior spaces. LED luminaires may initially cost more, but over time, their lifetime and energy efficiency result in lower overall operating expenses (Veitch, 2006).

Safety outcomes:

Optimizing illumination not only boosts workers efficiency but also makes a workplace much safer. This is especially true in the ceramics industry. Safety instructions and signs in all workplaces are easier to see in an emergency thanks to good illumination. Enhanced safety culture and less chance of fines are two benefits of optimizing illumination for compliance with occupational safety requirements in all workplaces. Improved illumination increases visibility and lowers the risk of worker and machinery accidents. For instance, the likelihood of hands becoming trapped in devices like presses or accidents brought on by tossing pleats into someone's eyes will be decreased. Workers are better able to identify possible risks, including spills or obstructions, and take preventative safety action. Lack of focus and fatigue can be avoided by using proper illumination, which also lowers glare and eye strain. Environments with good illumination encourage worker attentiveness and lower the possibility of errors that could result in mishaps. Adequate illumination reduces shadows where potential hazards could be overlooked, decreasing the risk of fire or other dangerous situations. Properly lit emergency exits and pathways ensure that workers can evacuate quickly and safely in case of an emergency. Improved visibility can speed up production by making it easier to identify problems quickly and streamline procedures (Dianat et al., 2013; Králiková et al., 2021).

Outlook:

With ongoing technological improvements and a strong emphasis on efficiency and sustainability, the ceramic industry's future for illumination optimization looks bright overall. To design a lighting system optimization plan, it is necessary to model the illumination failure. Additionally, this study recommends using more dependable optimization algorithms to identify the ideal lighting brightness levels for future research. Although the early research's use of rule-based heuristic algorithms provides a strong basis, more advanced and adaptive optimization algorithms can raise the lighting setups' accuracy and efficiency. Constructing illumination simulation programs and constructing illumination optimization procedures for design stages can be established with the help of public optimization platforms like GenOpt, Matlab, PyCharm, RStudio, jEPlus, and Mode Frontier.

5. Conclusion

This study assessed how to enhance worker performance in one of Iran's ceramic industries through illumination. The findings demonstrated that workplace illumination does not meet the requirements specified for each occupational duty. In this study, four factors—luminaire height suspended, light loss factor, number of luminaires, and luminous flux—were selected to optimize the illumination conditions of workplaces in the ceramic industry. The body preparation, press, glazing, and squaring workspaces were found to have the greatest disparity between the optimum and measured illuminance, suggesting that these areas should receive priority attention for illuminance improvement. It was determined that all workplaces after optimization would benefit from optimal illumination to an appropriate degree. Two key factors for maximizing illumination in workplaces were the luminaire's suspension height and the light loss factor. The findings of this study demonstrated that, in comparison to low-consumption fluorescent luminaire's, the application of LED technology can significantly enhance workplace illumination. In addition to the ceramic industry, other industries can benefit from the methods employed in this study to better manage and plan illumination when making decisions aimed at enhancing illumination.

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Code availability: Golden Software Surfer version 25.2.259, DIALux v4.13.0.2 and Design-Expert 13.0.5.0.

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Appendix

Table A1. Modeling of the scenarios to optimize illuminance in preparation of the ceramic body workplace.

Scenario	Light loss factor	Suspended height	Number of luminaires	Luminous flux	E_{ave}	E_{min}	E_{max}	E_{min}/E_{max}	E_{min}/E_{ave}
	Dimensionless	m	−	Lm/w	Lux				Dimensionless
1	−1 (0.5)	−1 (6)	−1 (54)	−1 (6300)	54	22	65	0.34	0.41
2	+1 (0.8)	−1 (6)	−1 (54)	−1 (6300)	86	35	104	0.34	0.41
3	−1 (0.5)	+1 (9)	−1 (54)	−1 (6300)	59	16	92	0.17	0.27
4	+1 (0.8)	+1 (9)	−1 (54)	−1 (6300)	94	25	147	0.17	0.27
5	−1 (0.5)	−1 (6)	+1 (120)	−1 (6300)	118	51	142	0.36	0.43
6	+1 (0.8)	−1 (6)	+1 (120)	−1 (6300)	189	82	227	0.36	0.43
7	−1 (0.5)	+1 (9)	+1 (120)	−1 (6300)	129	48	150	0.32	0.37
8	+1 (0.8)	+1 (9)	+1 (120)	−1 (6300)	206	76	240	0.37	0.32
9	−1 (0.5)	−1 (6)	−1 (54)	+1 (10,500)	89	36	108	0.34	0.41
10	+1 (0.8)	−1 (6)	−1 (54)	+1 (10,500)	143	58	173	0.34	0.41
11	−1 (0.5)	+1 (9)	−1 (54)	+1 (10,500)	98	26	153	0.17	0.27
12	+1 (0.8)	+1 (9)	−1 (54)	+1 (10,500)	157	42	245	0.17	0.27
13	−1 (0.5)	−1 (6)	+1 (120)	+1 (10,500)	197	85	236	0.36	0.43
14	+1 (0.8)	−1 (6)	+1 (120)	+1 (10,500)	315	136	378	0.36	0.43
15	−1 (0.5)	+1 (9)	+1 (120)	+1 (10,500)	214	79	250	0.32	0.37
16	+1 (0.8)	+1 (9)	+1 (120)	+1 (10,500)	343	127	400	0.32	0.37

Table A2. Modeling of the scenarios to optimize illumination in the press workplace.

Scenario	Light loss factor	Suspended height	Number of luminaires	Luminous flux	E_{ave}	E_{min}	E_{max}	E_{min}/E_{max}	E_{min}/E_{ave}
	Dimensionless	m	−	Lm/w	Lux				Dimensionless
1	−1 (0.5)	−1 (6)	−1 (36)	−1 (6300)	51	21	65	0.31	0.40
2	+1 (0.8)	−1 (6)	−1 (36)	−1 (6300)	82	33	104	0.31	0.40
3	−1 (0.5)	+1 (9)	−1 (36)	−1 (6300)	58	16	94	0.17	0.27
4	+1 (0.8)	+1 (9)	−1 (36)	−1 (6300)	92	25	150	0.17	0.27
5	−1 (0.5)	−1 (6)	+1 (72)	−1 (6300)	100	44	122	0.36	0.44
6	+1 (0.8)	−1 (6)	+1 (72)	−1 (6300)	160	70	195	0.36	0.44
7	−1 (0.5)	+1 (9)	+1 (72)	−1 (6300)	112	41	145	0.28	0.37
8	+1 (0.8)	+1 (9)	+1 (72)	−1 (6300)	180	66	233	0.28	0.37
9	−1 (0.5)	−1 (6)	−1 (36)	+1 (10,500)	85	34	109	0.31	0.40
10	+1 (0.8)	−1 (6)	−1 (36)	+1 (10,500)	136	55	174	0.31	0.40
11	−1 (0.5)	+1 (9)	−1 (36)	+1 (10,500)	96	26	157	0.17	0.27
12	+1 (0.8)	+1 (9)	−1 (36)	+1 (10,500)	154	42	251	0.17	0.27
13	−1 (0.5)	−1 (6)	+1 (72)	+1 (10,500)	167	73	203	0.36	0.44
14	+1 (0.8)	−1 (6)	+1 (72)	+1 (10,500)	267	117	325	0.36	0.44
15	−1 (0.5)	+1 (9)	+1 (72)	+1 (10,500)	187	69	242	0.28	0.37
16	+1 (0.8)	+1 (9)	+1 (72)	+1 (10,500)	300	110	388	0.28	0.37

Table A3. Modeling of the scenarios to optimize illuminance in glazing workplace.

Scenario	Light loss factor	Suspended height	Number of luminaires	Luminous flux	E_{ave}	E_{min}	E_{max}	E_{min}/E_{max}	E_{min}/E_{ave}
	Dimensionless	m	−	Lm/w	Lux				Dimensionless
1	−1 (0.5)	−1 (4)	−1 (18)	−1 (6300)	58	20	82	0.25	0.35
2	+1 (0.8)	−1 (4)	−1 (18)	−1 (6300)	93	32	131	0.35	0.25
3	−1 (0.5)	+1 (6)	−1 (18)	−1 (6300)	65	13	141	0.09	0.19
4	+1 (0.8)	+1 (6)	−1 (18)	−1 (6300)	105	20	225	0.09	0.19
5	−1 (0.5)	−1 (4)	+1 (30)	−1 (6300)	93	40	116	0.35	0.43
6	+1 (0.8)	−1 (4)	+1 (30)	−1 (6300)	149	65	186	0.35	0.43
7	−1 (0.5)	+1 (6)	+1 (30)	−1 (6300)	105	30	167	0.19	0.29
8	+1 (0.8)	+1 (6)	+1 (30)	−1 (6300)	168	49	267	0.18	0.29
9	−1 (0.5)	−1 (4)	−1 (18)	+1 (10,500)	97	34	136	0.25	0.35
10	+1 (0.8)	−1 (4)	−1 (18)	+1 (10,500)	155	54	218	0.25	0.35
11	−1 (0.5)	+1 (6)	−1 (18)	+1 (10,500)	109	21	235	0.09	0.19
12	+1 (0.8)	+1 (6)	−1 (18)	+1 (10,500)	174	34	376	0.09	0.19
13	−1 (0.5)	−1 (4)	+1 (30)	+1 (10,500)	156	67	194	0.35	0.43
14	+1 (0.8)	−1 (4)	+1 (30)	+1 (10,500)	250	108	310	0.35	0.43
15	−1 (0.5)	+1 (6)	+1 (30)	+1 (10,500)	175	51	279	0.18	0.29
16	+1 (0.8)	+1 (6)	+1 (30)	+1 (10,500)	280	81	446	0.18	0.29

Table A4. Modeling of the scenarios to optimize illuminance in the glaze line workplace.

Scenario	Light loss factor	Suspended height	Number of luminaires	Luminous flux	E_{ave}	E_{min}	E_{max}	E_{min}/E_{max}	E_{min}/E_{ave}
	Dimensionless	m	−	Lm/w	Lux				Dimensionless
1	−1 (0.5)	−1 (1)	−1 (80)	−1 (6300)	62	24	77	0.31	0.38
2	+1 (0.8)	−1 (1)	−1 (80)	−1 (6300)	100	38	123	0.31	0.38
3	−1 (0.5)	+1 (3)	−1 (80)	−1 (6300)	67	18	133	0.13	0.26
4	+1 (0.8)	+1 (3)	−1 (80)	−1 (6300)	107	28	213	0.13	0.26
5	−1 (0.5)	−1 (1)	+1 (143)	−1 (6300)	110	42	147	0.29	0.38
6	+1 (0.8)	−1 (1)	+1 (143)	−1 (6300)	176	68	235	0.29	0.38
7	−1 (0.5)	+1 (3)	+1 (143)	−1 (6300)	118	28	217	0.13	0.24
8	+1 (0.8)	+1 (3)	+1 (143)	−1 (6300)	188	45	348	0.24	0.13
9	−1 (0.5)	−1 (1)	−1 (80)	+1 (10,500)	104	40	129	0.31	0.38
10	+1 (0.8)	−1 (1)	−1 (80)	+1 (10,500)	167	64	206	0.31	0.38
11	−1 (0.5)	+1 (3)	−1 (80)	+1 (10,500)	112	30	222	0.13	0.26
12	+1 (0.8)	+1 (3)	−1 (80)	+1 (10,500)	179	47	355	0.13	0.26
13	−1 (0.5)	−1 (1)	+1 (143)	+1 (10,500)	184	71	245	0.29	0.38
14	+1 (0.8)	−1 (1)	+1 (143)	+1 (10,500)	294	113	391	0.29	0.38
15	−1 (0.5)	+1 (3)	+1 (143)	+1 (10,500)	196	46	362	0.13	0.24
16	+1 (0.8)	+1 (3)	+1 (143)	+1 (10,500)	314	74	580	0.13	0.24

Table A5. Modeling of the scenarios to optimize illuminance in the furnace workplace.

Scenario	Light loss factor	Suspended height	Number of luminaires	Luminous flux	E_{ave}	E_{min}	E_{max}	E_{min}/E_{max}	E_{min}/E_{ave}
	Dimensionless	m	−	Lm/w	Lux				Dimensionless
1	−1 (0.5)	−1 (1)	−1 (147)	−1 (6300)	56	19	77	0.25	0.34
2	+1 (0.8)	−1 (1)	−1 (147)	−1 (6300)	90	31	123	0.25	0.34
3	−1 (0.5)	+1 (3)	−1 (147)	−1 (6300)	60	13	133	0.10	0.21
4	+1 (0.8)	+1 (3)	−1 (147)	−1 (6300)	96	21	213	0.10	0.21
5	−1 (0.5)	−1 (1)	+1 (288)	−1 (6300)	107	34	187	0.18	0.31
6	+1 (0.8)	−1 (1)	+1 (288)	−1 (6300)	172	54	299	0.18	0.31
7	−1 (0.5)	+1 (3)	+1 (288)	−1 (6300)	114	18	302	0.06	0.16
8	+1 (0.8)	+1 (3)	+1 (288)	−1 (6300)	182	29	483	0.06	0.16
9	−1 (0.5)	−1 (1)	−1 (147)	+1 (10,500)	94	32	128	0.25	0.34
10	+1 (0.8)	−1 (1)	−1 (147)	+1 (10,500)	151	52	204	0.25	0.34
11	−1 (0.5)	+1 (3)	−1 (147)	+1 (10,500)	100	21	222	0.10	0.21
12	+1 (0.8)	+1 (3)	−1 (147)	+1 (10,500)	160	34	356	0.10	0.21
13	−1 (0.5)	−1 (1)	+1 (288)	+1 (10,500)	179	56	312	0.18	0.31
14	+1 (0.8)	−1 (1)	+1 (288)	+1 (10,500)	286	90	499	0.18	0.31
15	−1 (0.5)	+1 (3)	+1 (288)	+1 (10,500)	189	31	503	0.06	0.16
16	+1 (0.8)	+1 (3)	+1 (288)	+1 (10,500)	303	49	805	0.06	0.16

Table A6. Modeling of the scenarios to optimize illumination in squaring workplace.

Scenario	Light loss factor	Suspended height	Number of luminaires	Luminous flux	E_{ave}	E_{min}	E_{max}	E_{min}/E_{max}	E_{min}/E_{ave}
	Dimensionless	m	−	Lm/w	Lux				Dimensionless
1	−1 (0.5)	−1 (1)	−1 (18)	−1 (6300)	40	14	58	0.24	0.35
2	+1 (0.8)	−1 (1)	−1 (18)	−1 (6300)	64	22	93	0.24	0.35
3	−1 (0.5)	+1 (3)	−1 (18)	−1 (6300)	45	8.4	123	0.07	0.19
4	+1 (0.8)	+1 (3)	−1 (18)	−1 (6300)	71	13	196	0.07	0.19
5	−1 (0.5)	−1 (1)	+1 (48)	−1 (6300)	102	43	130	0.33	0.42
6	+1 (0.8)	−1 (1)	+1 (48)	−1 (6300)	163	69	208	0.33	0.42
7	−1 (0.5)	+1 (3)	+1 (48)	−1 (6300)	113	31	188	0.17	0.28
8	+1 (0.8)	+1 (3)	+1 (48)	−1 (6300)	181	50	301	0.17	0.28
9	−1 (0.5)	−1 (1)	−1 (18)	+1 (10,500)	67	23	97	0.24	0.35
10	+1 (0.8)	−1 (1)	−1 (18)	+1 (10,500)	106	37	155	0.24	0.35
11	−1 (0.5)	+1 (3)	−1 (18)	+1 (10,500)	74	14	205	0.07	0.19
12	+1 (0.8)	+1 (3)	−1 (18)	+1 (10,500)	119	22	327	0.07	0.19
13	−1 (0.5)	−1 (1)	+1 (48)	+1 (10,500)	170	72	216	0.33	0.42
14	+1 (0.8)	−1 (1)	+1 (48)	+1 (10,500)	272	115	346	0.33	0.42
15	−1 (0.5)	+1 (3)	+1 (48)	+1 (10,500)	208	9.5	1621	0.01	0.05
16	+1 (0.8)	+1 (3)	+1 (48)	+1 (10,500)	302	84	501	0.17	0.28

Table A7. Modeling of the scenarios to optimize illumination in packing workplace.

Scenario	Light loss factor	Suspended height	Number of luminaires	Luminous flux	E_{ave}	E_{min}	E_{max}	E_{min}/E_{max}	E_{min}/E_{ave}
	Dimensionless	m	−	Lm/w	Lux				Dimensionless
1	−1 (0.5)	−1 (1)	−1 (52)	−1 (6300)	89	39	107	0.36	0.44
2	+1 (0.8)	−1 (1)	−1 (52)	−1 (6300)	143	63	172	0.36	0.44
3	−1 (0.5)	+1 (3)	−1 (52)	−1 (6300)	99	36	154	0.23	0.36
4	+1 (0.8)	+1 (3)	−1 (52)	−1 (6300)	159	57	246	0.23	0.36
5	−1 (0.5)	−1 (1)	+1 (63)	−1 (6300)	108	46	142	0.33	0.43
6	+1 (0.8)	−1 (1)	+1 (63)	−1 (6300)	173	74	227	0.33	0.43
7	−1 (0.5)	+1 (3)	+1 (63)	−1 (6300)	120	31	208	0.15	0.26
8	+1 (0.8)	+1 (3)	+1 (63)	−1 (6300)	191	50	333	0.15	0.26
9	−1 (0.5)	−1 (1)	−1 (52)	+1 (10,500)	149	65	179	0.36	0.44
10	+1 (0.8)	−1 (1)	−1 (52)	+1 (10,500)	239	104	286	0.36	0.44
11	−1 (0.5)	+1 (3)	−1 (52)	+1 (10,500)	166	60	256	0.23	0.36
12	+1 (0.8)	+1 (3)	−1 (52)	+1 (10,500)	265	95	409	0.23	0.36
13	−1 (0.5)	−1 (1)	+1 (63)	+1 (10,500)	180	77	236	0.33	0.43
14	+1 (0.8)	−1 (1)	+1 (63)	+1 (10,500)	288	123	378	0.33	0.43
15	−1 (0.5)	+1 (3)	+1 (63)	+1 (10,500)	199	52	347	0.15	0.26
16	+1 (0.8)	+1 (3)	+1 (63)	+1 (10,500)	319	83	555	0.15	0.26

Table A8. ANOVA for average illuminance of the preparation of the ceramic body workplace base on reduced 2FI model.

Source	Sum of squares	df	Mean square	*F*-value	*p*-value Prob > *F*	Result
Model	1.073E + 005	7	15,325.42	342.95	< 0.0001	significant
A-A	20,664.06	1	20,664.06	462.41	< 0.0001	
B-B	742.56	1	742.56	16.62	0.0036	
C-C	54,172.56	1	54,172.56	1212.25	< 0.0001	
D-D	24,102.56	1	24,102.56	539.36	< 0.0001	
AC	2889.06	1	2889.06	64.65	< 0.0001	
AD	1314.06	1	1314.06	29.41	0.0006	
CD	3393.06	1	3393.06	75.93	< 0.0001	
Residual	357.50	8	44.69			
Cor Total	1.076E + 005	15				

Table A9. ANOVA for average illuminance of the press workplace based on reduced 2FI model.

Source	Sum of squares	df	Mean square	*F*-value	*p*-value Prob > *F*	Result
Model	74,180.44	7	10,597.21	245.02	< 0.0001	significant
A-A	16,576.56	1	16,576.56	383.27	16,576.56	
B-B	1072.56	1	1072.56	24.80	1072.56	

Table A9. (*Continued*).

Source	Sum of squares	df	Mean square	*F*-value	*p*-value Prob > *F*	Result
C-C	32,310.06	1	32,310.06	747.05	32,310.06	
D-D	19,390.56	1	19,390.56	448.34	19,390.56	
AC	1743.06	1	1743.06	40.30	1743.06	
AD	1040.06	1	1040.06	24.05	1040.06	
CD	2047.56	1	2047.56	47.34	2047.56	
Residual	346.00	8	43.25			
Cor Total	74,526.44	15				

Table A10. ANOVA for average illuminance of the glazing workplace based on reduced 2FI model.

Source	Sum of squares	df	Mean square	*F*-value	*p*-value Prob > *F*	Result
Model	57,210.25	7	8172.89	272.71	< 0.0001	significant
A-A	16,641.00	1	16,641.00	555.28	< 0.0001	
B-B	1056.25	1	1056.25	35.25	0.0003	
C-C	16,900.00	1	16,900.00	563.92	< 0.0001	
D-D	19,600.00	1	19,600.00	654.01	< 0.0001	
AC	900.00	1	900.00	30.03	0.0006	
AD	1024.00	1	1024.00	34.17	0.0004	
CD	1089.00	1	1089.00	36.34	0.0003	
Residual	239.75	8	29.97			
Cor Total	57,450.00	15				

Table A11. ANOVA for average illuminance of the glaze line workplace base on reduced 2FI model.

Source	Sum of squares	df	Mean square	*F*-value	*p*-value Prob > *F*	Result
Model	78,763.75	7	11,251.96	511.45	< 0.0001	significant
A-A	20,449.00	1	20,449.00	929.50	< 0.0001	
B-B	441.00	1	441.00	20.05	0.0021	
C-C	29,070.25	1	29,070.25	1321.37	< 0.0001	
D-D	24,180.25	1	24,180.25	1099.10	< 0.0001	
AC	1521.00	1	1521.00	69.14	< 0.0001	
AD	1296.00	1	1296.00	58.91	< 0.0001	
CD	1806.25	1	1806.25	82.10	< 0.0001	
Residual	176.00	8	22.00			
Cor Total	78,939.75	15				

Table A12. ANOVA for average illuminance of the furnace workplace based on reduced 2FI model.

Source	Sum of squares	df	Mean square	*F*-value	*p*-value Prob > *F*	Result
Model	77,715.44	7	11,102.21	551.66	< 0.0001	significant
A-A	18,292.56	1	18,292.56	908.95	< 0.0001	
B-B	297.56	1	297.56	14.79	0.0049	
C-C	32,851.56	1	32,851.56	1632.38	< 0.0001	
D-D	21,389.06	1	21,389.06	1062.81	< 0.0001	
AC	1743.06	1	1743.06	86.61	< 0.0001	
AD	1139.06	1	1139.06	56.60	< 0.0001	
CD	2002.56	1	2002.56	99.51	< 0.0001	
Residual	161.00	8	20.13			
Cor Total	77,876.44	15				

Table A13. ANOVA for average illuminance of the squaring workplace based on reduced 2FI model.

Source	Sum of squares	df	Mean square	*F*-value	*p*-value Prob > *F*	Result
Model	92,836.50	8	11,604.56	266.83	< 0.0001	significant
A-A	13,167.56	1	13,167.56	302.76	< 0.0001	
B-B	1040.06	1	1040.06	23.91	0.0018	
C-C	53,476.56	1	53,476.56	1229.60	< 0.0001	
D-D	18,157.56	1	18,157.56	417.50	< 0.0001	
AC	2280.06	1	2280.06	52.43	0.0002	
AD	637.56	1	637.56	14.66	0.0065	
BC	264.06	1	264.06	6.07	0.0432	
CD	3813.06	1	3813.06	87.67	< 0.0001	
Residual	304.44	7	43.49			
Cor Total	93,140.94	15				

Table A14. ANOVA for average illumination of the packing workplace based on reduced 2FI model.

Source	Sum of squares	df	Mean square	*F*-value	*p*-value Prob > *F*	Result
Model	68,779.56	9	7642.17	1416.31	< 0.0001	significant
A-A	27,805.56	1	27,805.56	5153.15	< 0.0001	
B-B	1387.56	1	1387.56	257.15	< 0.0001	
C-C	4522.56	1	4522.56	838.16	< 0.0001	
D-D	32,670.56	1	32,670.56	6054.78	< 0.0001	
AB	68.06	1	68.06	12.61	0.0120	
AC	232.56	1	232.56	43.10	0.0006	
AD	1743.06	1	1743.06	323.04	< 0.0001	
BD	85.56	1	85.56	15.86	0.0073	

Table A14. (*Continued*).

Source	**Sum of squares**	**df**	**Mean square**	***F*-value**	***p*-value Prob > *F***	**Result**
CD	264.06	1	264.06	48.94	0.0004	
Residual	32.38	6	5.40			
Cor Total	68,811.94	15				

Table A15. Model evaluation indices for data prediction.

Workplace	***R*-Squared**	**Adjusted *R*-Squared**	**Predicted *R*-Squared**	**Adequate Precision**
Preparation of the ceramic body	0.9967	0.9938	0.9867	59.129
Press	0.9954	0.9913	0.9814	51.664
Glazing	0.9958	0.9922	0.9833	55.735
Glaze line	0.9978	0.9958	0.9911	73.870
Furnace	0.9979	0.9961	0.9917	75.659
Squaring	0.9967	0.9930	0.9829	51.859
Packing	0.9995	0.9988	0.9967	123.066