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Ergonomic analysis of the classroom using the LiDAR system

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Abstract: This article presents an innovative method of using LiDAR technology to analyze and measure the current ergonomic conditions of a university classroom. The purpose of this research is to provide a detailed analysis of the working environment and to identify collision points, proposing changes and improvements to meet the rules and standards of ergonomic correctness. The outcome of this analysis is a 3D model containing detailed information about the current state of the environment. This model was subsequently utilized to identify ergonomic deficiencies, which formed the basis for proposed modifications. The article also discusses the applications of modern LiDAR technology, its functions, and accessibility for ordinary users, as well as accessibility on individual software platforms.

1 Introduction

LiDAR (Light Detection and Ranging) is a remote sensing technology that uses pulsed laser light to measure distances and create highly detailed and accurate 3D maps of the surrounding environment. The basic principle of LiDAR involves sending out laser pulses and measuring the time it takes for the light to reflect back after hitting an object. By knowing the speed of light and the time it takes for the laser to return, the distance to the object can be calculated with high precision [1].

The LiDAR system typically consists of the following components:

1. Laser Source: The device emits short and powerful laser pulses, usually in the near-infrared spectrum.
2. Scanner and Optics: The laser pulses are directed toward the target area using scanning mirrors and lenses, allowing the LiDAR sensor to cover a wide field of view.
3. Photodetector: The sensor measures the intensity of the reflected laser light, capturing the time of flight information.
4. GPS Receiver: Integrated with the LiDAR system to obtain accurate geolocation data for each point in the generated point cloud.
5. Inertial Measurement Unit (IMU): This component records the orientation and motion of the LiDAR sensor, enabling precise spatial alignment of the collected data.

The characteristics of this method are speed, non-contact, precision, complexity, and simplicity of the work, which takes place automatically after setting the correct parameters in the device [2].

The output from the scan is the scanned object displayed in the form of point clouds (Figure 1), which can be further studied in applications or worked with and modified in CAD/CAM systems [3].

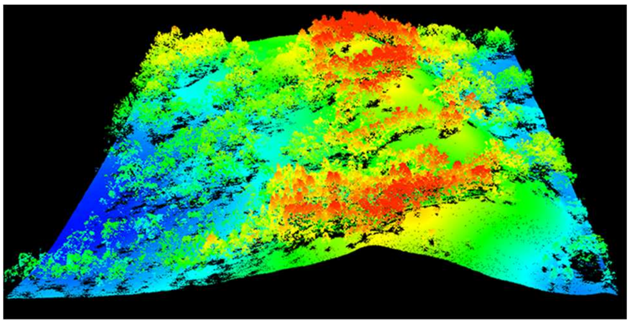

Figure 1 Point cloud captured by the LiDAR system [2]

Professional practical use of LiDAR is versatile in today's advanced age. This technology speeds up and simplifies many processes that would otherwise take unnecessary time and excessive human effort. This technology has found application in Topographic Mapping, Environmental Monitoring, Autonomous Vehicles, Urban Planning, Archaeology and Cultural Heritage, Forensics, and Accident Reconstruction [2,3].

1.1 Overview of selected applications for 3D scanning of rooms using the LiDAR system

Several room scanning applications were selected for this study. When choosing applications, the focus was on their usability in interiors, measuring tools, and, last but not least, on exporting scans to STL, OBJ or other types of files for surface mesh. Some types such as OBJ contain not only export to surface mesh but also texture data at each point of the scan, which facilitates additional evaluation in external applications such as e.g. GOM Inspect (Carl Zeiss, Germany), which provide significantly wider options for the dimensional and geometric evaluation of scans and their parts.

Obtained scans or their parts (models of equipment, devices, people, etc.) can be used in environment design software, simulation software, architecture, and other fields. As part of the research, their use was aimed at 3D scanning the laboratory, obtaining measures for ergonomic evaluation of its suitability, and subsequent evaluation of the laboratory based on the publication "Architects' Data" publication by the author Ernst Neufert [4].

For research purposes, SiteScape (SiteScape Inc., New York, USA), Scaniverse (Niantic, Inc., San Francisco, USA), Canvas (Occipital, Inc., Colorado, USA), Polycam (Polycam, Altadena, USA) and 3D scanner app (Laan Labs, NewYork, USA) software were used as reference software. Table 1 shows the basic parameters of the selected software.

Table 1 Summary of selected application parameters

Title	Site Scape	Scaniverse	Canvas	Polycam	3D Scanner App
Demo	Free	Free	Free scan	Free	Free
PRO	$37,50 12/ month $49,99/ year	Free	2D $0,1/ft 3D $0,15/ft	$6,99/ month $54,99/ year	Free
iOS	✓	✓	✓	✓	✓
Android	X	X	X	✓	X
Interior	✓	✓	✓	✓	✓
Exterior	X	✓	X	✓	✓
Rating	4,6/5	4,8/5	4,6/5	3,5/5	4,8/5

1.1.1 SiteScape

SiteScape is one of the most used LiDAR applications. It is available for download only for devices with the iOS operating system, i.e. iPhone 12/13 Pro, iPhone 12/13 Pro Max or iPad Pro 2020/2021 from Apple Inc. SiteScape was created by SiteScape Inc. The application is created to facilitate work in the fields of construction, engineering and architecture at a professional or amateur level. When scanning, it is possible to choose from two scanning methods, the usual method or Multi-scanning. The normal scan function simply starts scanning the surrounding space and collecting data until we end the scan with a button on the display. This scan cannot be interrupted with the option of continuing data collection later. The multi-scanning function works by gradually creating scans of the areas we are interested in. These scans can be synced to iCloud, and after logging into a desktop or laptop computer, they can be downloaded and then manually assembled and arranged to look like the complex of scanned spaces in reality. This process is accompanied by the help of artificial intelligence in the application, which automatically filters out the noise between the scans and helps us merge these scans into one (Figure 2). The application can scan a maximum of 500 m².

Among the disadvantages of this application can be included the inability of the application to capture nature and the external environment in such a way that the captured data creates an image and a surface that would be further usable [5].

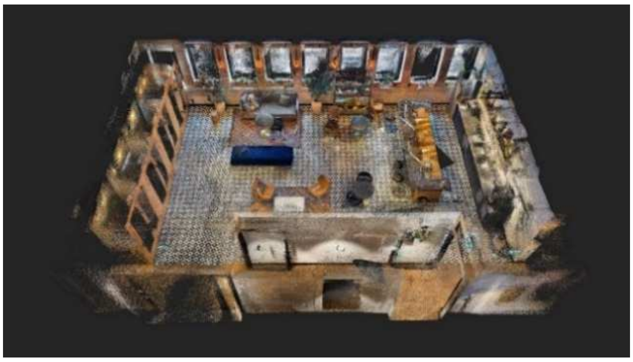

Figure 1 3D scan of the room by SiteScape [6]

1.1.2 Scaniverse

Scaniverse is an app from Toolbox AI that is fully compatible with iOS devices only. The devices that have full support are iPhone 12/13 Pro/Pro Max or for iPad Pro 2020 and other devices of higher orders. The advantages of this application include the ability to scan anything in space - for example, a room, an object even nature, and the outdoor environment with high accuracy. Another advantage of Scaniverse is that the generated scans can be shared with any other devices, where the user can view them through the browser installed on the device. The variety of export options is very refined, as models can be further imported into 3D modeling software such as Blender, Maya or SolidWorks. It is also possible to import 3D models into game creation programs such as Unity and Unreal Engine and use them, for example, to create game textures [7].

1.1.3 Canvas

The Canvas application is fully compatible only with devices from Apple Inc., specifically for iPhone 12/13 Pro/Pro Max devices or for iPad Pro 2020 and other devices of higher orders. The application is created by Occipital, Inc.

This application is mainly used in the professional sphere. It offers many features, making it ideal for design firms, kitchen and bathroom renovators, general contractors, interior designers, architects and other engineering industries to work with. Canvas can be used to scan 3D models of rooms and floor plans based on recorded measurement data after scanning.

Among the advantages of this application is that the application can create a 3D model from the measured data, from which the measurements of all objects that are scanned can then be read. The creators state the accuracy of the measurement with this application to be 3 cm, but it depends on the precision of the user.

The created model (Figure 3) can later be opened in AutoCAD and worked with. Export of models is possible in formats for CAD and BIM software, SketchUp, Chief Architect, Autodesk Revit, or 2020 Design programs [8]. Individual scans and models can also be shared and explored on any device.

Figure 2 3D scan of the room by Canvas [9]

1.1.4 Polycam

The Polycam application is an application from the App Store for iOS devices and is also compatible with Android devices, where it can be downloaded from the Google Play Store. For full use of the application's capabilities, it is necessary to download the application to a compatible device with a LiDAR sensor, specifically for models from Apple Inc. iPhone 12/13 Pro/Pro Max or for iPad Pro 2020 and other higher-end devices or for Android devices such as Samsung Galaxy S10 5G, S20+ and S20 [10]. The application was developed by Polycam.

The application has a simple interface and the process of obtaining data for the creation of a 3-dimensional model can be carried out in two ways.

1. Method of recording material:
   a. by starting the video,
   b. by gradually creating photos (photogrammetry).

2. In-depth data collection method:
   a. using LiDAR,
   b. without using LiDAR.

The speed of data generation is indicated by the manufacturer at 42 m^2/4 min. After finishing data processing, it is possible to view the model directly in the application.

The advantage of this application is the ability to create plans as images that can be shared between multiple devices at will. The accuracy of this application is given by the creators at 3 cm. A big advantage is also that the community that uses this application includes several thousand members, with whom you can actively communicate and advise via Discord or Gmail in case of problems during use. This application is capable of scanning both the interior and exterior. Export of scanned data is possible in several formats, for example, .obj, .png, .glb, .fbx, .dae, .stl, .usdz, .dxf, .ply, .laz, .pts, .gltf, .xyz. It is also possible to save a recording video or individual screenshots [11].

1.1.5 3D Scanner App

LiDAR scanning is also possible using the 3D Scanner App. This application is only compatible with devices from Apple Inc. with the iOS operating system, namely for iPhone, iPad, and iPod touch with iOS 14.0 and higher and for Mac with iOS 12.0 and higher. The creator of this application is Laan Labs.

3D Scanner App is designed and developed for 3D and CAD designers and architects.

Export from this program is possible in several formats. For example OBJ, STL, USDZ, WEB Link, GLTF, GLB, PCD, PLY, PTS, XYZ, LAS, e57, Sketchfab, DAE and FBX. It is also possible to send completed scans via the Apple iMessage application.

2 Methodology of scanning rooms and objects

Based on the review, four room scanning applications were selected.

Before the actual scanning, there are several steps to be taken to ensure the best possible result. These actions are aimed both at the device used for scanning and at the scanned environment. Individual steps are shown in Figure 4.

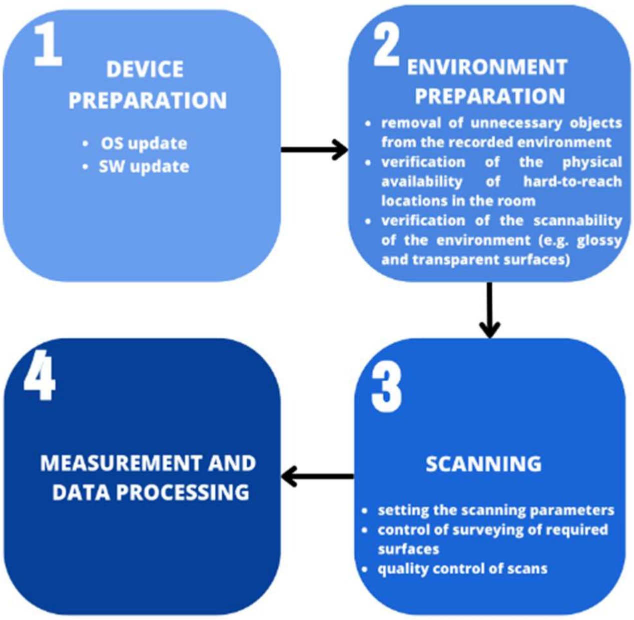

Figure 3 Room scanning methodology

As soon as the **SiteScape** application is turned on, it displays the activated camera, settings button, scan start, and gallery as the main menu. Before scanning, it is necessary to set the point density. From the options small, medium, and high density, large was chosen for the most accurate results. Another important setting is the point size when scanning (Point size), the largest point size was also chosen due to the size of the classroom. Additional options in the settings require the purchase of the Pro version of this application.

After pressing the button, the scanning is activated and the contours and shapes of the scanned surfaces are created on the screen with the simultaneous slow movement. The scanning process is limited by the amount of data and will automatically end when it is full. Scans that have been successfully performed will be displayed in the form of a 3D model after the scan is complete. This model can be exported and synchronized with the Cloud (Sync to Cloud). In the available gallery, it is possible to view all performed scans and continue to work with them.

Before starting the scan in **Scaniverse**, it is important to go into the settings and adjust some of them. When we have the application set up correctly, to activate the scan, click on the bottom bar, and start a new scan. A window will appear in which we choose the size of the object to be scanned. You can choose a small object (Small Object - e.g. food, toys, animals, flowers...), a medium object (Medium Object - e.g. people, vehicles, furniture...), and a large object or area (Large Object/Area - e.g. room, building, outdoor space...). The correct selection of the object from the menu does not affect the accuracy of the data, but only the default distance to which we want to shoot. Since the goal was to scan a classroom, the large object option was chosen. Before activating the scan, it is possible to set the maximum data scanning distance (Range). The range offered is from 0.3 m to 5 m, while a distance of 5 m was chosen due to the size of the room.

After activating the scan, it was necessary to scan the entire room with smooth, slow movements. If the movement was too fast, a warning appeared on the screen to slow down. It is possible to pause the scanning process and during it, it is possible to move freely in the space. However, when starting it again, it is important to have the device pointed at least partially at the already scanned surface, otherwise there may be a problem with the alignment of the scans. On the screen during scanning, there is a white-red striped field that indicates unscanned surfaces that need attention - for example, from a different angle or distance. The already scanned area is displayed on the screen as it is in reality.

After the scan is finished, the option to choose from 3 different modes for processing the scanned data will be displayed. The accuracy of the generated data depends on it. The first, fast mode "Speed" is intended for a quick generation with the smallest accuracy of the generated data to 10 mm, the second "area" mode is intended for generating larger areas with an accuracy of 5 mm, and therefore this option was used. The last "detail" mode uses photogrammetry and is recommended for displaying textured objects.

After choosing the desired mode, the application creates a network (Mesh) and the process is finished. A 3D model will appear on the screen. Finally, it is possible to save the scanned data even before generating the 3D model (Save Raw Data). It is important to keep them in case additional processing in another mode is required.

This 3D model is saved to the library in the application where it can be viewed. The application offers the possibility of editing, displaying in artificial reality, measurement of individual lengths, and the possibility of sharing the 3D model.

After opening the **Canvas** application, the main menu (Homes) will appear, where we can choose an already created or create a new project. Contains a library of all projects. All three room scans were inserted into the created project. In the main menu there are also orders (Orders), where you can save generated 3D CAD models and plans of scanned rooms, help (Help), where you can find a tutorial for use, and settings (Settings). In the settings, it is possible to determine the units of measurement and create models (Units). The meter (Meters) was chosen as the main unit.

Before starting the recording, it is important to adjust the room so that the conditions are optimal for creating the most faithful 3D model. It is necessary to turn on the light in the room, open the blinds and curtains and close the windows and doors. According to the instructions provided by the manufacturers of the Canvas application, it is necessary to start scanning from the corner of the room, on furniture, or on another surface that is not completely flat and monochromatic, such as a wall. After activating the scanning process, a real image of the environment at which the scanner is aimed is displayed on the screen. Along with it, gray triangles are also created indicating the area that has already been scanned. To correctly scan the room, it is necessary to move horizontally up, to the side, horizontally down, and continue again to the side that we chose the first time. The distance from the scanned surface should be 0.9144 - 3.048 m at all times. This procedure is repeated until the entire surface of the room is scanned. The surface of the mirrors is omitted, only the area around them is scanned.

The scan can be interrupted or terminated at any time with the pause button. The location that was last scanned will remain on the screen until it is restarted. It is necessary to continue scanning on it. After finishing the scanning of the surface, we have the option to generate a CAD plan (Get CAD), for which it is necessary to pay, or we can see a scan without colors (View Scan) - that is, a gray scanned surface. The application allows you to apply colors to the scan for free so that it looks like in reality.

Scans can be viewed from a point of view as if the observer were inside the object, outside, or from above. Exporting scans for free is limited to a URL link that allows the scan to be shared and viewed on other devices. The application allows measuring the lengths and contents of surfaces in the preview of the scans using a toolbar that can be pulled from the right side of the screen with an arrow.

Scanning can be interrupted or terminated at any time by pressing the "pause" button. The location that was last scanned will remain on the screen until it is restarted.

It is necessary to continue scanning it. After finishing the scanning of the surface, the option to generate a CAD plan (Get CAD) is displayed, for which it is necessary to pay, or we can see a scan without texture (View Scan) - that is, a gray scanned surface. The application allows you to apply colors to the scan for free so that it looks like in reality.

Scans can be viewed from a point of view as if the observer were inside the object, outside, or from above. Exporting scans for free is limited to a URL link that allows the scan to be shared and viewed on other devices. The application allows measuring the lengths and contents of surfaces in the preview of the scans using a toolbar that can be pulled from the right side of the screen with an arrow.

The 3D Scanner App facilitates various scanning methods. Upon opening, it presents the camera along with options to select the scanning method, initiate scanning, and access old scans. We opted for LiDAR scanning, which involves displaying a grid of triangles on the surface. Scanned triangles retain their authentic color, while non-scanned ones appear in red. While scanning, adherence to the fundamental rules of slow and smooth movement is crucial. The creators caution against scanning the same location twice, citing potential issues. Additionally, they note that the app might not accurately capture small surfaces, like pens or table legs, possibly interpreting them as empty space**.**

After the scan is finished, a color scan will be displayed composed of the texture of the surface that was scanned. Along with it, a table will be displayed from which you can choose how the scan should be processed (Process Scan). There are HD, Medium, Fast or Custom processes to choose from. The selected format was HD to keep the scan data as accurate as possible. This generated true color scan can be exported in various formats with the Share button. Scans can also be edited and smoothed with various functions that appear under the button edit (Edit) and more (More). It is also possible to measure individual lengths in the created scans, this function is activated with the Measure button.

3 Ergonomic analysis of the classroom from a 3D scan

Nowadays, there is an excessive load and overloading of the human body in workplaces due to incorrect ergonomic design of the equipment in classrooms, laboratories, and other workplaces. Such workplaces do not meet the standards according to which they should have been originally designed. By means of the LiDAR technology built into the applications and their other functions, it is possible to simplify the design of an ergonomically suitable environment or to transform an originally unsatisfactory one.

3.1 Ergonomics of the classroom

When defining the basic ergonomic parameters of the classroom, the publication “Architects' Data” by the author Neufert et al. It was the version from 2019 that was used. The publication is considered among architects as a source of standards in the professional community. The following parameters were selected for evaluation [4].

a) Workplace:
i. Table (depth, width, height),
ii. A chair.

b) Parameters for the classroom:
i. Dimension behind the table,
ii. The dimension behind the table in the last row,
iii. The size of the main street,
iv. Space for manipulating the window,
v. Access to the sink,
vi. Normative m^2 for one workplace,
vii. The dimension between the board and the first row of benches.

Figure 5 shows the overall scan of the laboratory with the measured values between the selected locations.

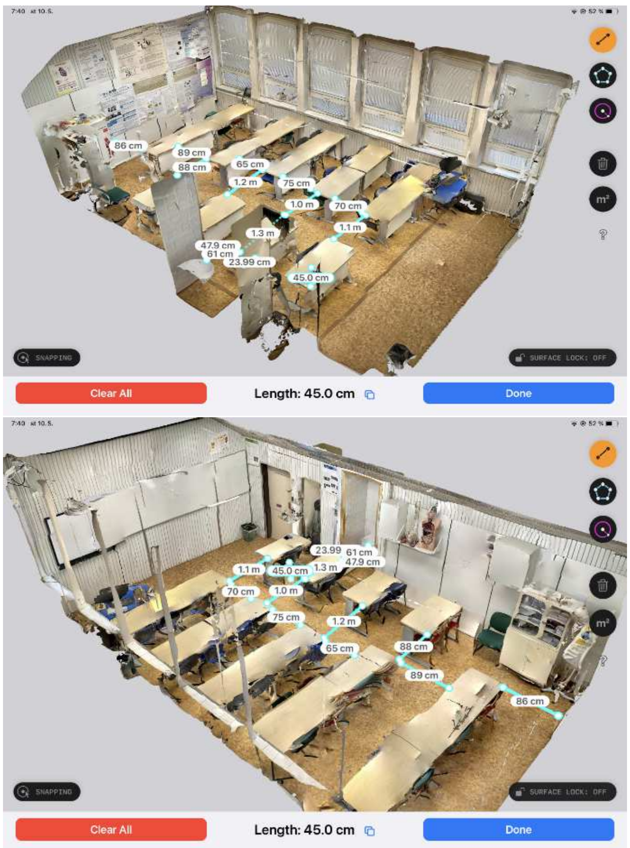

Figure 4 3D scan of the classroom with dimensions

Table 2 shows standard values and actual values for selected parameters with an assessment of whether the value is sufficient, partially sufficient, or insufficient.

Table 1 Evaluation of compliance with standards in classroom

Parameter number	Parameter name	Actual dimension	Standard*	sufficient /insufficient
1A	Table - height	0,75 m	0,75 m	complies with the standards
1B	Table for 2 people - width	1,3 m		
1B	Working width for 1 person	0,65 m	0,58 m - 0,70 m	complies with the standards
1C	Table - depth	0,65 m	0,65 m	complies with the standards
2	Chair height	0,45 m	od 0,42 m do 0,52 m	complies with the standards
3A	Dimension behind the table	od 0,65 m do 0,89 m	0,85 m	partially meets the standards
3B	The dimension behind the table in the last row	0,86 m	0,95 m	Does not complies with the standards
4	Central aisle	od 0,88 m do1,2 m	od 0,9 m do 1,20 m	partially complies the standards
5	Space for manipulating the window	0 m	0,55 m	Does not complies with the standards
6	Access to the sink	0,61 m	od 0,80 m do 0,90 m	Does not complies with the standards
7	Classroom area 47.32 m^2 / number of workplaces	1,69 m2	2 m2	partially complies the standards

*The mentioned standards were taken from publication Architects' Data by the author Ernst Neufert [4]

Figure 6 shows the proposed floor plan of the room with dimensions.

Figure 5 Ergonomic design of the classroom

4 Results and discussion

From the scans of the classrooms that have been created, it is possible to read the data needed to design the ideal ergonomically suitable environment for the student's workplace and the correct parameters for the classroom. It was found that the height of the tables is 0.75 m, which meets the prescribed standard. The working width and depth of the table were measured to be 0.65 m and 0.65 m, respectively. These values correspond to standard sizes.

When measuring the parameters for the classroom, the dimension behind the desk was measured, i.e. the space for sitting, which varied from 0.65 m to 0.89 m between the individual benches. This dimension should have a minimum value of 0.85 m and thus only partially meets the prescribed value. The dimension behind the table in the last row should be defined at 0.95 m with the assumption that it will be necessary to walk smoothly along the wall behind it. The dimension behind this table was measured at 0.86 m, which does not meet the minimum standard. The size of the main aisle in the classroom also varied from 0.88 m to 1.2 m. The standardized size of the main street should be from 0.9 m to 1.20 m and thus partially meets the requirements. The space for manipulating the window was 0 m. In this space, there should have been an aisle with a width of 0.55 m for proper handling. This space is also important for maintaining hygiene in the classroom through ventilation. In front of the sink in the classroom there was a table with chairs and it prevented access to it. According to the standards, access to the sink should be ensured by an aisle with a width of 0.80 m to 0.90 m. The distance between the first bench and the board should be around 2 m, but this dimension was not precisely defined in the “Architects' Data” publication [4]. As the last parameter, we calculated the area of the classroom. We divided this dimension by the number of jobs. According to the current layout of the classroom, we found that the working area for one student is 1.69 m^2, which does not meet the required standards.

Based on the set of standards, the norm for one workplace in our type of classroom is recommended and defined at 2 m^2. The size of our room is 47.32 m^2 and the recommended number of workplaces is 23.66. We compared this data with the result of the arrangement resulting from the application of rules i - iv.

5 Conclusion

In conclusion, the analysis of ergonomics in a university classroom through the implementation of 3D scanning technology has proven to be an invaluable and transformative tool. By employing 3D scanning techniques, we were able to comprehensively capture and evaluate the spatial layout, furniture arrangement. The data collected provided measurements and visual representations, enabling a comprehensive understanding of the current ergonomic conditions and potential areas for improvement.

The findings of this study revealed several crucial insights. Firstly, it was evident that the existing classroom design had both strengths and weaknesses in terms of ergonomic functionality. Through this analysis, we were able to recommend targeted interventions to enhance the overall classroom ergonomics. By optimizing furniture placement, adjusting seat heights, and incorporating adjustable features, we can create an environment that promotes better posture, reduces physical strain, and supports overall student comfort. Additionally, the insights gained from this study can guide the future design of university classrooms to prioritize ergonomics from the outset, benefiting both students and educators. The integration of such technology can revolutionize the way we approach classroom design and ergonomic evaluations, leading to more inclusive, comfortable, and conducive learning spaces.

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