How to accomplish Education Spaces where Students can read Subject Matter anywhere in the Classroom

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1. ABSTRACT

Delft University of Technology (TU Delft) has been changing its management over learning spaces enormously. Student numbers have doubled since two decades resulting in a situation that classes could not fit any longer within education spaces of their own faculty building. Slowly a dynamic shift came into being where larger classes were scheduled over different university buildings. At the same time, a new challenge came up because the operation of the existing lecture halls and classrooms differed enormously over campus.

In 2014 a Taskforce Education Spaces was formed to cope with this shifting situation. They came up with a 10 years transformation plan proposing a two-fold strategy: 1) governance structure for all parties involved in education spaces (education, real estate, IT, facilities), and 2) guidelines defined in a Cookbook Education Spaces based on contemporary pedagogies in collaboration with teaching staff and students.

Today, TU Delft holds over 26.500 students and the numbers continue to grow. Lecture halls and classrooms are managed centrally, and the building policy aims at mono-functional buildings henceforth i.e. no more combined premises for research and education. TU Delft has been deciding to put education first with building projects. Quality of education features within education spaces took its place next to seat capacity, readability became very important.

This paper describes education features that influence readability including the visualization with our interactive education spaces configurator TUDesc.

2. INTRODUCTION

Universities obtain new education buildings to cope with a growing student population, to facilitate modern teaching and learning practices, and to replace outdated premises. Regularly, misconceptions exist between space designers and end-users. Common examples are insufficient clear heights within classrooms, obstructed sightlines, incorrect lighting plans that frustrate projection and unforeseen sun's rays on screen in spring and autumn. Such misconceptions come forth from ill-defined commissioning at the very beginning of the building process, but all have negative influence on readability. For such reason a governance model was set up so that all university parties who have their share in education spaces talk to each other and use the same language when commissioning third parties.

Readability and sightlines are undervalued parameters in designing education spaces. No clear definitions are available, only rules of thumb, but students must be able to read subject matter anywhere in the classroom. Students should be able to fully concentrate on understanding the subject matter and not be distracted by unreadable formulas or strained necks. Clear commissioning with proper readability and sightlines for education spaces was main reason for Delft University of Technology (TU Delft) to put requirements on paper. It has led to our freely available Cookbook

Education Spaces describing the current education practices with its space typologies and requirements, and study workplaces. The Cookbook's requirements still start discussions but now before construction starts, preventing problems before they occur.

However, interpreting the cookbook tables appeared to be difficult. Visualizing readability and sightlines with our TU Delft Education Spaces Configurator (TUDesc) makes it easier. Moreover, TUDesc saves time and money by defining an education space yourself, it reviews versions instantly preventing successive meetings, and it checks the proposed requirements easily during acceptance. With TUDesc, one can manage lecture halls and classrooms with focus on readability. Configured education spaces can be stored and printed.

3. GOVERNANCE STRUCTURE FOR EDUCATION SPACES

The departments of Education and Student Affairs (ESA), Campus Real Estate (CRE), and ICT and Campus Facility Management (ICT&CFM) have recognised that interdisciplinary cooperation was vital to realise futureproof education spaces. The takeover of learning spaces from faculties and placing them under central control demanded for rearranging learning spaces management, implementing new processes, rewriting design requirements, setting-up lifecycle maintenance, and reordering support. Henceforth the department of Education & Student Affairs is accountable for all learning spaces and will be commissioning new education buildings, monitoring quality in general, take decisions about renovation, seat capacity and its local support. Teacher training and user support are part of this too. Campus Real Estate will be accountable for the totals of building capacity and the building bound installations and ICT & Facility Management will be accountable for the AV-IT systems and infrastructure.

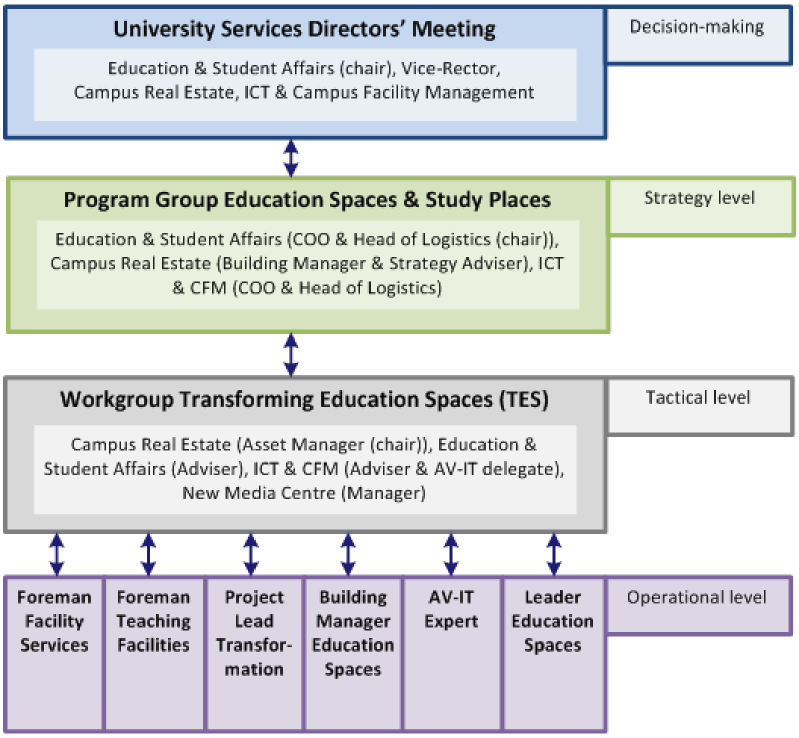


Figure 1: Governance Model for TU Delft Education Spaces

The informal but professional way in which the many experts from different departments worked together in the beginning of the project has been transformed into a formal organization. Figure 1 shows the current organization over the several parties. Linking pins are placed on every level, from decision making down to the operational level. Interdepartmental cooperation was and still is the key factor for success. Today the university partners talk as if they are one and straight definitions and requirements are commissioned to architects and builders resulting in education buildings and spaces as we want them. The Program Group Education Spaces & Study Places advises on a strategy level while the Workgroup Transforming Education Spaces (TES) operates as hub for all related processes.

4. READABILITY IN LECTURE HALLS AND CLASSROOMS

Chalkboard-pedagogy is essential for teaching a talking-writing way of reasoning at our scientific and technical university. Natural science lecturers love the chalkboard when explaining theorems and proofs. While thinking aloud they simultaneously produce and write arguments in successive order on the board, which can be digital or erasable whiteboard too. In such way, their reasoning becomes visible. Students see the process and structure of the systematic arguments that appear on the board, they gain the ability to recognise patterns and interconnections with this chalkboard pedagogy. Students have to take notes, because they must think with their eyes and hands themselves (Greiffenhagen 2014). Therefore, being able to discern every presented character is essential.

Lecturers were surprised when they were asked how large their characters are if they write them on a chalkboard. They just shrugged their shoulders when they replied that it depends on the depth of a lecture hall. In the case that students cannot discern the written characters they complain and the character height is adjusted to their need. Thus, over the years of lecturing a natural estimation of character height versus readability is gained.

A literature study was conducted and ergonomic professors were interviewed to collect proper rules for character heights in education spaces. Results were that only rules of thumb exist, such as a character height versus distance ratio of 1 to 200 or five times the diagonal of a screen. Henceforth, empirical fieldwork was done to measure the character stroke height of subject matter in twentyone lecture halls during breaks. The written character stroke heights were measured with a ruler in relation to the distance from chalkboard to last row in the lecture hall. They varied between 7 and 10 centimetres of height resulting in viewing angles from 17 to 23 arc minutes (Zanden 2014). One arc minute represents the $1/360^{th}$ part of a circle (1 degree) divided by 60 minutes, resulting in 0.0167 degrees.

Next to written characters also PowerPoint presentations with education content were collected and analysed in relation to the screen dimensions. In general a slide was divided in 15 percent for the title and 10 percent for the banner. The remaining 75 percent held an average of 10 sentences, formulas, phrases with 9 space lines resulting in viewing angles from 17 to 20 arc minutes for projected images. Light emitting displays had 14 to 17 arc minutes. However, they had good readability due to better contrast.

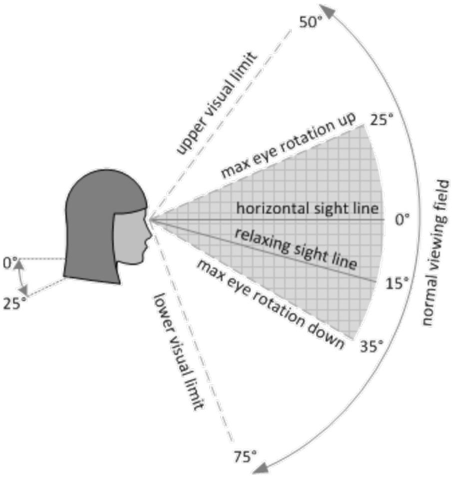
These figures were compared with the works of ophthalmologists and opticians who follow the Snellen and its evolved eye charts to determine a good sight. A vision of 100 percent is the same as having a visual acuity (visus) of 1, which corresponds to 1 arc minute. That 1 arc minute is being taken as the minimum perceiving ability of the eye. Good sight as reference is about 17 arc minutes. Subtitles at television and Youtube channels are between 13 to 20 arc minutes.

In order to check these figures a study was followed with empirical tests in several lecture halls with a tool especially developed to determine a firm guideline, see a simple tool to test readability: http://homepage.tudelft.nl/9c41c/Readability/ReadabilityTool4EducationSpaces.htm. This tool is made of PowerPoint slides with referenced distances and heights. It was presented with texts for the standardized fonts Calibri 11 for Word and Excel documents and Calibri 24 for presentation subject matter. It contains the distance values for the viewing angles 20, 17, 14, and 1. The practical tests with about thirty lecturers, students, staff and AV integrator personnel approved the values. Native language words could be recognized when angles were even as small as 10 arc minute with peering eyes, but an average of 14 arc minutes delivered good readability. Seventeen arc minutes are advised if one wants to read unfamiliar characters such as formula symbols or texts in a foreign language.

5. READABILITY IS INFLUENCED BY SEVERAL VARIABLES

Readability is more than character height presented on the screen in relation to the distance of a lecture hall. Other ergonomic variables play significant roles, such as strain free sightlines from the viewer's position, eye height dependent on applied furniture and hall, and the quality and contrast of the presented image influenced by daylight and artificial lighting.

5.1. VERTICAL VIEWING ANGLE



Human eyes can rotate about 25 degrees upwards and 35 degrees downwards without moving the neck joint. However, when reading texts one has to focus on a single text line. Hence, the head moves according to a vertical pattern when reading texts from a presentation screen. An ergonomic complete overview can be found in "The Measure of Man and Woman: Human Factors in Design" (Tilley 2002).

The vertical angle is at its largest for students sitting at the front row of the classroom. Their neck joint tilts the largest angle to follow texts on the projection screen. A neck joint can easily be moved upwards up to 25 degrees as Figure 2 shows. Tilting the neck joint above 30 degrees is possible but very fatiguing. In order to unburden the neck joint of students at the front row of the classroom and to prevent overload it is advised to follow a vertical angle of 25 degrees.

Figure 2: Simplified overview of the vertical viewing field

5.2. HORIZONTAL VIEWING ANGLE

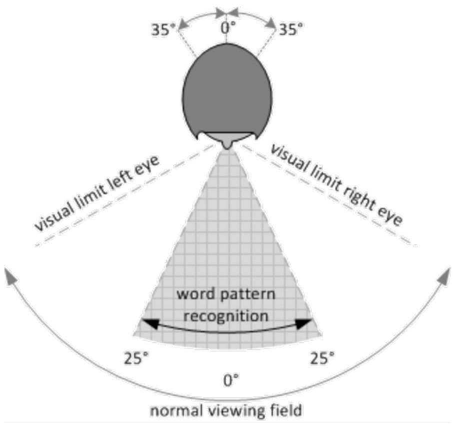


Figure 3 shows the horizontal viewing field. Sight is at best at the central axis of the eyes. Only within plus and minus 10 degrees of that central axis the reading takes place. With a horizontal eye rotation from plus to minus 15 degrees the text recognition happens between 25 degrees to the left up to 25 degrees to the right.

Research of C.J. Snijders c.s. about neck stress shows that rotation up to 35 degrees is easy and does not cost any physical exertion, however, angles over 35 degrees cause severe neck stress (Snijders, Hoek van Dijke et al. 1991).

When students sit at the front row, but at the far sides, their neck has to rotate overproportionally in order to read the presented text from the presentation screen. They turn their body too, which in the end may lead to physical complaints.

Figure 3: Simplified overview of the horizontal viewing field

In order to prevent physical complaints in the classroom it is advised to consider a maximum viewing angle of about 60 degrees, which is 35 degrees neck and 25 degrees eye rotation combined. Dependent on furniture safety regulations revolving chairs may help.

5.3. EYE HEIGHT

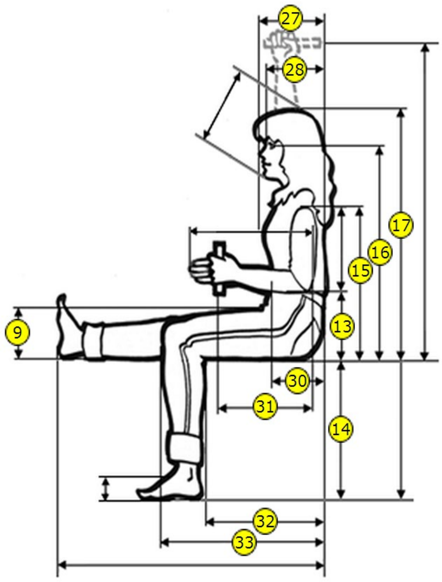


Figure 4: Human measurements of a sitting person.

Students sit next to each other as well as behind each other, but sightlines in flat level classrooms are different than for tiered lecture halls. Dependent on the position of the projection screen most of the students have to move sideways to follow the presented information. The position of the projection screen on the front wall may differ dependent on the hall's arrangement and its visitors. The DINED antropometric database of Delft University of Technology, founded by Dr. J.F.M. Molenbroek, keeps human dimensions for ergonomic purposes of people for already forty years, see http://dined.io.tudelft.nl/en,dined2004,302.

People databases with human dimensions for different ergonomic purposes (standing, sitting, working) are available world wide. Mounting the screen at a proper height, called floor-to-underside, is derived from the antropometric figures.

It may vary between a minimum height of about 130 cm to a maximum of approximately 155 cm for Dutch students. A floor to-underside height of 140 cm will do in most cases for flat-level classrooms. However, if a lecturer is walking along than a floor-to-underside of minimal 210 cm is advised.

5.4. QUALITY AND CONTRAST OF PRESENTED IMAGES OR WRITTEN CONTENT

Chalkboards have excellent readability because of the white chalk written on a dark background. Erasable white boards on the other hand have a reading distance of only about 8 metres after which the white background "eats" the written characters. Especially used markers and aging boards have negative influence on the readability.

The perceived quality of a projected image is dependent on multiple factors, such as the extent of daylight and floodlight, extent of blinds, artificial light, combination of projector's ANSI lumen, projection screen material or LED display. All parts count their own influence onto the projected image quality. Figure 1 shows an indicative overview of the several components within the Image Effect Chain.

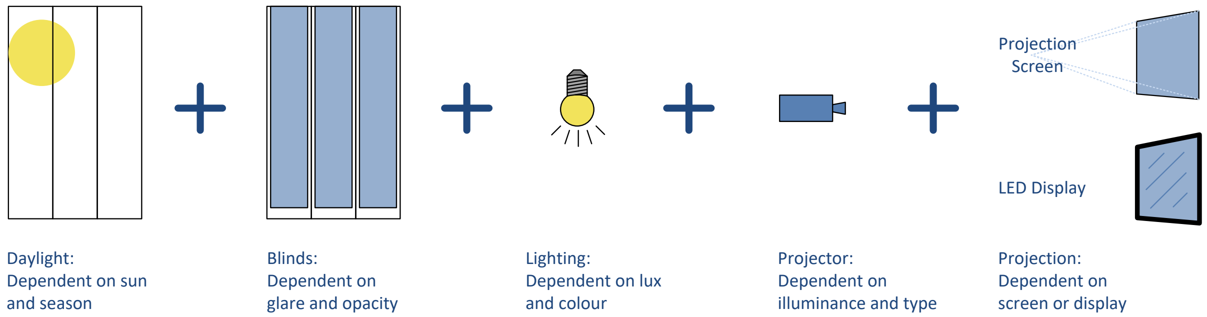


Figure 5: Several parts within the image effect chain have their influence on the projected image quality

Trade organisation AVIXA (Audio Visual and Integrated Experience Association), formerly known as InfoComm, has published an ANSI (American National Standards Institute) norm in order to standardise the perceived quality of projected images. The norm is called "Projected Image System Contrast Ratio" (PISCR), documented as ANSI/InfoComm 3M-2011 and generally accepted within the audio-visual domain.

Despite the fact that computer images are displayed more often with black characters on a white background, it is advised to use white characters on a dark background when writing and presenting formulas on an interactive whiteboard or SMARTboard. On the one hand white characters show an excellent readable result; on the other hand it delivers a comfortable picture.

6. COOKBOOK EDUCATION SPACES

The collected requirements and space parameters were drawn up with faculty and supporting staff in a comprehensive brochure called Cookbook Education Spaces. It describes current educational practices and study work places, with space typologies and requirements. The Cookbook Education Spaces has a multifaceted objective:

- To provide an overview of education spaces and related teaching practices for instructors and lecturers.
- To offer requirements per education space as checklist for designers and other external parties.
- To set guidelines for standardization, operation and usability for AV and support staff.

The first part describes four types of contemporary pedagogies that were determined with delegates of faculty and staff:

- The Frontal Teaching is teacher-centred. The lecturer situated at the front elaborates on a subject, shows a presentation on the screen or chalks a formula on the board. The expert explains and elaborates about a topic, and the students take home individual work or group assignments. Active learning components are gradually being brought into these practices, such as direct interaction with a feedback tool.
- Mixed Practice is student-centred. Students follow classes with alternating practices, such as a frontal introduction and subsequently working in student groups on assignments. The teacher and assistants walk around to help where needed.
- Collaborating focuses on team work and group assignments. Students must apply their knowledge in projects and learn to communicate, collaborate and cooperate in teams while they are coached by the instructor.
- Testing is for students to demonstrate what they have learned. Digital testing has the advantage to support both campus exams and tests for online classes and MOOCs. Digital exam halls can also be used for computer practical.

The second part shows space typologies and a portfolio of pictures. The third part describes the space requirements such as readability figures places in tables. The collected data was analysed and transformed into readability figures placed in tables in the Cookbook Education Spaces. An example is given in Table 1.

Table 1: Advised minimum dimensions for projected image at given reading distances

Reading distance	Projected Character Height (17'- 20')	Minimum Projected Image Dimensions	Minimum Ceiling Height in Tiered Lecture Halls	Minimum Ceiling Height in Flat Level Lecture Halls
8 m	4.0 - 4.7	180 * 101 cm		100 + 140 + 20 = 260
10 m	4.9 - 5.8	240 * 135 cm		135 + 140 + 20 = 295
12 m	5.9 - 7.0	280 * 158 cm	158 + 210 + 20 = 388 cm	160 + 140 + 20 = 320
14 m	6.9 - 8.1	330 * 186 cm	186 + 210 + 20 = 416 cm	190 + 140 + 20 = 350
16 m	7.9 - 9.3	380 * 214 cm	214 + 210 + 20 = 444 cm	215 + 140 + 20 = 375
18 m	8.9 - 10.5	430 * 242 cm	242 + 210 + 20 = 472 cm	-
20 m	9.9 - 11.6	480 * 270 cm	270 + 210 + 20 = 500 cm	-
22 m	10.9 - 12.8	530 * 298 cm	298 + 210 + 20 = 528 cm	-
24 m	11.9 - 14.0	580 * 326 cm	326 + 210 + 20 = 556 cm	-

The fourth part describes three types of study workplaces that were determined with delegates from student bodies and student union:

- Silent study places to concentrate for many hours in a silent area.
- Touchdown study places for temporary self-study or short-term group work.
- Meeting places for various social encounters, such as informal meetings or conversation.

7. VISUALIZING READABILITY AND SIGHTLINES MAKES IT EASIER

Interpreting the readability tables is not always straightforward for third parties, e.g. figures about reading distance and related ceiling height are continuously variable. It is a gliding scale but only a few values are presented in the tables. Inter- and extrapolation make persons doubting and hesitating to make decisions of which they are not certain about how it will work out for the education space.

For such reason the Cookbook Education Spaces has been taken a step further. Misinterpretations must be prevented for parties working in lecture halls and classrooms. An interactive tool visualizes important education features, such as readability, sightlines, capacity and accessibility based on ergonomic values. With our application called TUDesc (TU Delft Education Spaces Configurator) one is able to define the several parameters that are important for proper readability. The TU Delft Education Spaces Configurator is available online at tudesc.com, but only in licensed versions.

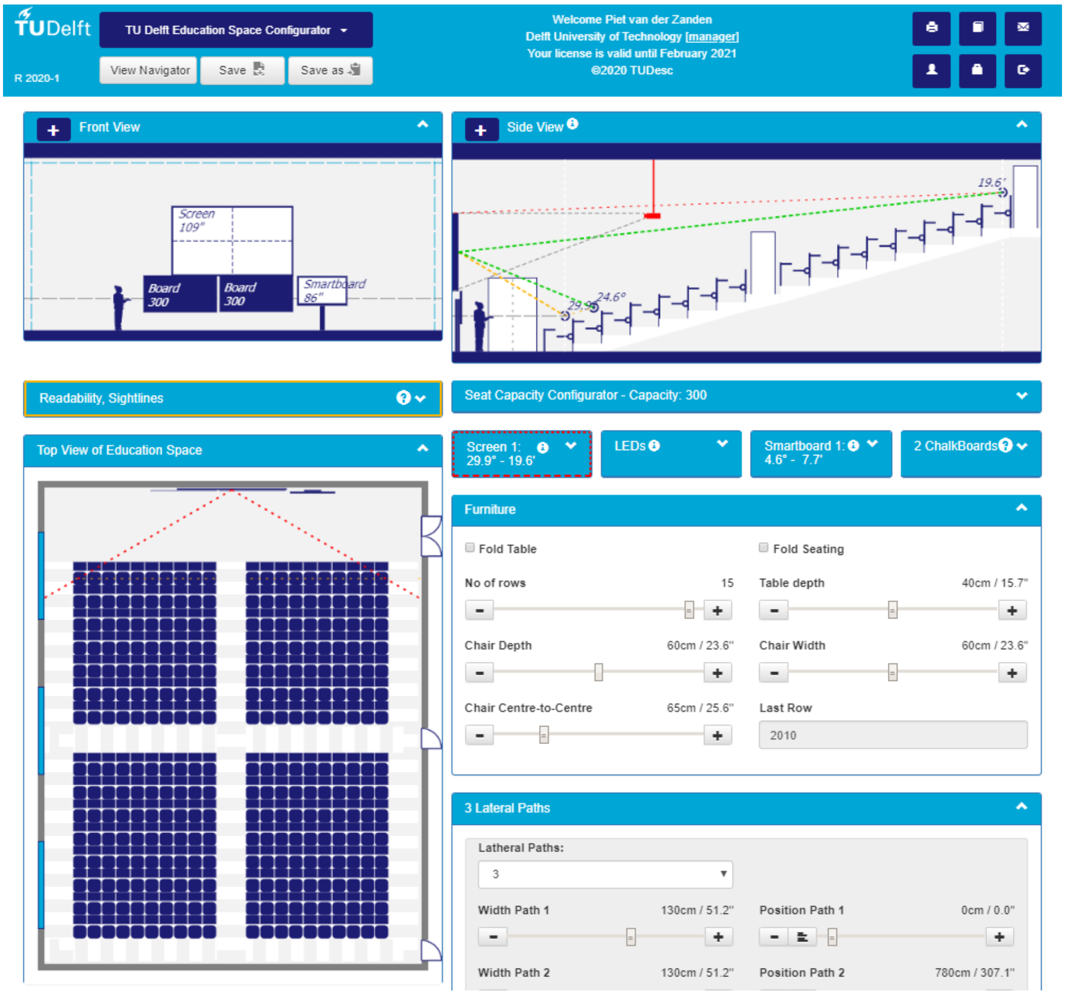


Figure 6: Impression of a tiered lecture hall in TUDesc

At the moment TUDesc supports three classroom layouts: tiered lecture hall as is showed in Figure 6, flat-level classroom as Figure 7 shows and terraced classroom as in Figure 8. Amphitheatres follow soon. Plans are to extend it with simple and free add-ons (tap, basin, fire extinguisher, sensors, AV-rack, speakers, etc) and more complicated modules (sun rays, daylight, assets, furniture), and to combine it with other education related applications aiming at education spaces, such as esviewer.tudelft.nl, which holds an overview with all the centrally managed lecture halls and classrooms.

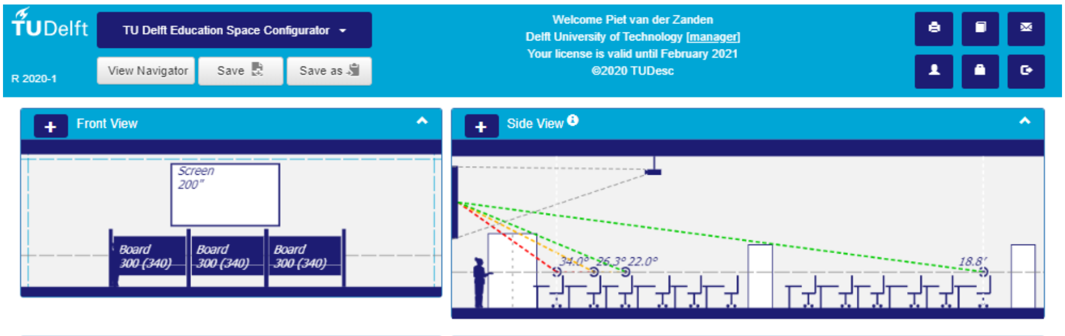


Figure 7: Impression of a flat-level classroom in TUDesc

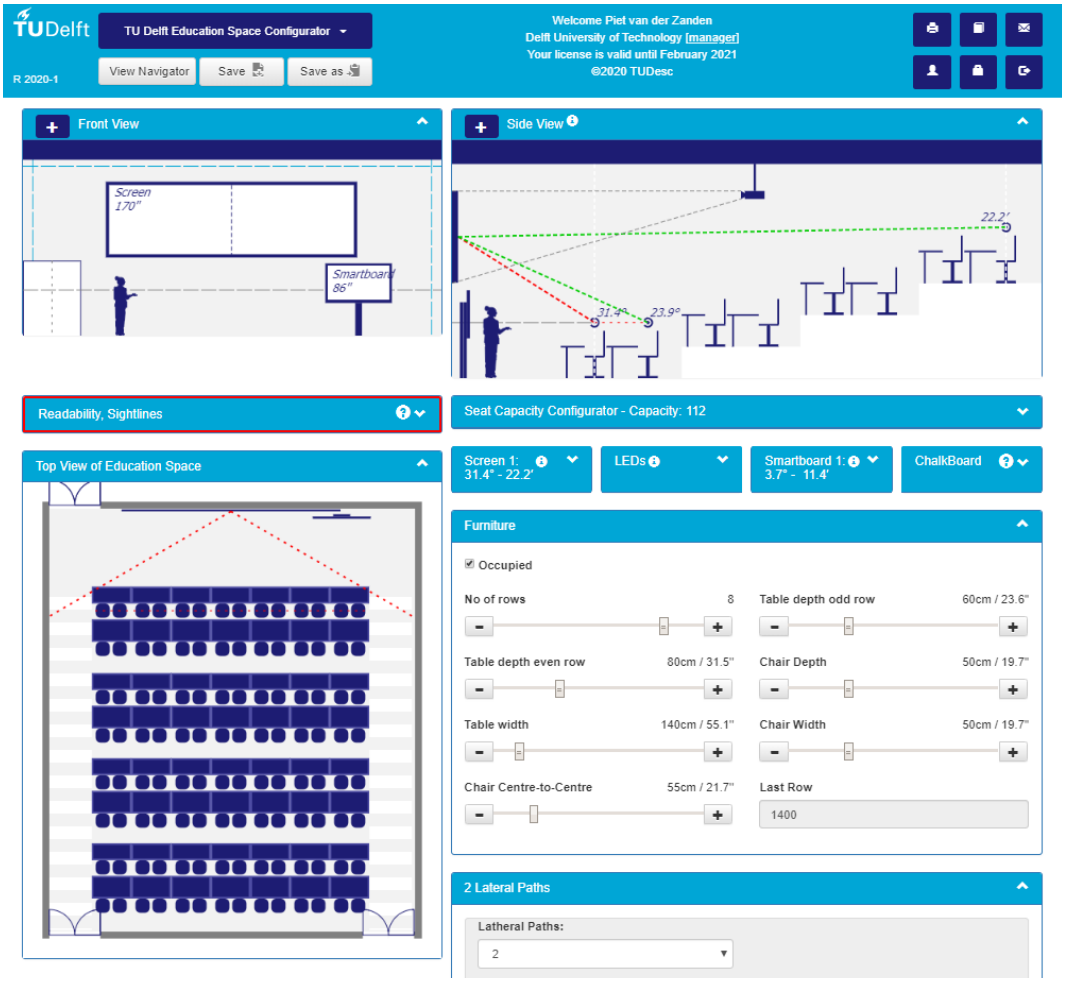


Figure 8: Impression of a terraced classroom in TUDesc

Due to consequences from the COVID 19 virus TUDesc is extended with a social distance function. Lecture halls with fixed furniture have a straight forward algoritm but flat level classrooms can be optimized by varying the gap between the tables, the row passage between succeeding tables and chairs, and the number of lateral and cross paths. Figure 9 shows an impression. At the left is the normal layout with 240 seats, the second figure shows social distancing following a regular algoritm having only 60 seats, the third figure is the optimized layout with 121 seats, and the figure on the right shows a printed floorplan with exact dimensions to instruct facility services.

Figure 9: Social Distancing in a flat-level classroom: normal, regular, optimized and printed floorplan

8. CONCLUSION

Delft University of Technology has about 350 education spaces of which two hundred are centrally organised and scheduled. Over 160 spaces are already upgraded with state-of-the-art equipment, varying from basic projector and chalkboard up to quad signal presentation systems with digital writing. Moreover, they follow an identical operation so that lecturers have no problem working in any other lecture hall.

At the start of this complex transformation many experts from different departments worked together in an informal but professional way. Now, after five years of intensive cooperation the processes have become clear and specialists are (re)positioned within formal organisation. Linking pins are stationed on every level, from decision making to the operational level. This interdepartmental cooperation was and still is the first key factor for success.

The second success factor is the cookbook Education Spaces. The guidelines written in it are very clear for following certain requirements but not too tight so varying remains possible. As a result different pedagogies work out much better and to everybody's convenience system errors have dropped tremendously. A survey with 35 teaching staff and 880 students delivered very satisfying figures with a score of 7.8 out of 10 from the teaching staff and 7.7 out of 10 from students. In short:

- Teachers find the appropriate affordances including identical operation units a true improvement and are very satisfied.
- System errors have dropped tremendously from once a week to zero.
- Digital writing and multi signal presentation changes the frontal pedagogy in a more blended way.
- Mixed practices with flexible lay-outs have been facilitating multiple ways of active learning, interaction and collaborative settings.
- Study places are used more intensively. Social coherence and internalisation tend to attract students to campus more often.

TUDesc is developed to make the requirements written in the Cookbook Education Spaces better to grasp with an interactive education space configurator. Funstionalities will be added to make TUDesc an all comprehensive tool to manage the quality and quantity of lecture halls and classrooms, reasoning from out of education.

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10. AUTHORS' BIOGRAPHIES

Dr. ing. A.H.W. (Piet) van der Zanden is education expert with special focus on AV-IT and interior issues of teaching and learning spaces. He has an initiating role in the design and development of education facilities. He advises about audio-visual, pedagogical, ergonomic and technical issues, and is involved in feasibility and usability studies.

Piet has devised the four-quadrant pedagogy, which is facilitated by a quad signal presentation system combined with an interactive smartboard. He does training and evaluation and discusses pedagogical approaches that come within reach because of it.

Pedagogy challenges for the years to come are collaborative design labs for ill-structured engineering projects, and hybrid classrooms to bridge physical and virtual students in one and the same class.

Piet earned his doctor degree in 2009 about The Facillitating University; Positioning the Next Generation Educational Technology at Delft University of Technology. The study is aimed at how higher education might cope with the current and upcoming pressures of technology on education. Developments that have had or have an influence in the shaping process of higher education were addressed, a quantitative study on growth patterns and users' uses from 289 virtual learning environments was conducted, and elaboration on educational technology with the gained insights was carried out to deliver a picture of the future educational practice, which we like to call Learning mall.

2009 to date: Education expert with focus on teaching and learning environments for Higher Education at University Corporate Office ICT of Delft University of Technology (TU Delft). 2004-2009: Project manager & Adviser ICT at Shared Service Centre ICT, support for education, research and organisation. PhD student at Faculty of Technology, Policy & Management, Section EduTec at TU Delft. Project management of interuniversity projects, advice aiming at ICT within higher education, member of E-merge consortium steering group, and coaching of master students and fellow PhD students.

1996-2004: Senior project leader Information Technology at Department of Technical Support. Adviser at Faculty of Technology, Policy & Management at TU Delft. Responsible for the domain of ICT in Higher Education and its authoritative ICT in Education (ICTE) projects, member of ICTE Bureau at TU Delft, instigator for interfaculty and interuniversity contacts, and acquisition of innovative ICTE projects. Indirectly responsible for university policy in the ICTE domain.

1990-1996: Team leader / Adviser Information Technology at Central Electronic Department of TU Delft. Manager of Computer & Local Area Networking group. Responsible for integral management concerning relations, finance, people, resources, training, project management and monitoring.

Responsible for external communication and advice aiming at ill-structured problems for strategic decisions.

1986-1990: Team leader / medical computer engineer at Leyenburg Hospital in The Hague. Team leader of the diagnostic group, adviser for purchase of medical and computer systems. Supervising electrical hazard and (ionising) radiation safety. Making enquiries for medical specialists, doing development, design, modifications and repairs on machines and programs, maintenance planning and quality assurance.

1984-1986: Instrumentation engineer / seismic operator at Delft Geophysical. Team leader of electronic engineers, repair team and field operators. Responsible for all equipment applied for seismic data-acquisition of three seismic field units nation-wide. Development of dedicated instruments, operation and maintenance of digital seismic recorders.

1980-1984: Electronic engineer at Ground Water Survey of TNO in Delft. Designing, building, testing, modifying and repairing equipment used for geophysical and geohydrological fieldwork and research.

Ing. M.J. (Marcel) Heijink is software developer for innovative applications. Marcel was Lead developer for Online Learning website of Delft University of Technology. He designed and created several LTI plugins for BrightSpace Collaborative Learning Environment and is skilled in Django Framework, Python, JavaScript, MYSQL, Docker, Kubernetes, REST framework.

2016 to date: Software developer at TU Delft in ICT innovation team.

2000-2016: Software developer for the institute's planning tool, BlackBoard Plugins, OAuth2 Server. Co-Developer for Etude (Digital Testing System with item banking and automatic test drawing used as institute's centralised system). Applied skills: Python, Java, WebServices, C#, GWT, C++, DCOM.

1989-2000: Hardware & Software developer at TU Delft. Graphic User Interface for international Laser Ranging System applied by Transportable Integrated Geodetic Observatory (TIGO). FPGA programmer (Field Programmable Gate Arrays) including expansion boards and controlling software. Co-Developer for Sonate (Digital Testing System to be used by individual teachers to assess the quality of their tests and questions). Applied skills: C++, X Motif, C, Assembly, MFC, DCOM, MSSQL.