

New Revolving Furniture for Mixed Practices and Interactive Classes

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Synopsis

Formal education spaces are available in two main construction forms: tiered and sloped floors for lecture halls and theaters, and flat-level floors for instruction classes and project spaces [1]. Furniture was fixed to the ground since long, only from the second half of the 21st century flat-level classrooms became more easy to rearrange. Especially new pedagogy for primary and secondary education asked for changeable furniture arrangements in class. Discussions about flexible arrangements within higher education were initiated only since the last decade [2,3]. They first aimed at learning spaces based on informal settings and later at ‘interactive classes’ based on team-based learning and flipped classroom pedagogies [4]. Also these higher education pedagogies need flexible furniture, however, not similar to the type of furniture as is applied for primary and secondary education.

The demand for another sort of flexible furniture comes forth from the multiple directions in which higher education has been developing since the 1960s. An enormous growth of student numbers has taken place due to easier access and improved educational grants. Such ‘massification’ resulted in a request for larger lecture halls. ‘Mobility’ and ‘heterogeneity’, and the ‘major-minor’ system due to the ‘Bologna Process’ for European higher education, resulted in greater ‘personalisation’, which on its turn demands smaller learning spaces [5]. Additionally, interactive classes prefer convertible settings, i.e. frontal instruction and group work within a single learning space.

Occupation and utilisation figures taught us that current educational practices increasingly do not match the present available spaces anymore [6]. Lecture halls and classrooms were once designed for frontal instruction only. Now, increasingly group assignments are practiced. Thus, a master thesis was commissioned to design a prototype of revolving classroom furniture, called Flexstool®.

Together with manufacturer EromesMarko (www.eromesmarko.nl) in the Netherlands a successive pilot project was set up to investigate such new higher education furniture to facilitate frontal instruction and group work in one go. Two different null series were produced and situated in the Wim Crowel Hall at Delft University of Technology in the Netherlands.

This paper reports about the different steps from idea to production, i.e. the in-between improvements, insights in educational, technical and ergonomic uses and its eighteen months of experience in education thus far.

1 Introducing Convertible Furniture to Flexibilise Classrooms

Massification and personalisation are contradictory movements for occupancy and utilisation of lecture halls and classrooms. Growing cohorts demand larger lecture halls, while minor tracks and supplemental courses demand smaller classrooms to facilitate group work. As a result it is hard for universities to make appropriate policy for the coming years because it is unknown what seat capacity is needed during such change of higher education practices. In general, new buildings and renovations take longer periods to realise than the annual variation of student numbers and foreseeing changes in curriculums.

Universities mostly choose the seat capacity option to cope with massification; more seats to facilitate more students appears to be a straight forward strategy. However, a study aiming at occupation and utilisation of lecture halls over an academic year revealed that for 64 percent of the available lecture halls a reservation was made from curriculum. During that specific year only 49 percent were actually occupied, from which not more than 32 percent of the seats were used [6]. Results and additional interviews indicated that the applied educational practices did not match the present available spaces anymore. It is not the number of seats that count, but the classroom’s utilisation.

Frontal instruction was the practised pedagogy for long. Now, in an increasingly way, group assignments are practiced. As a result, we can observe that large student cohorts follow introductory courses at the start of the academic year leaving the smaller classrooms unattended. Successively, group assignments are conducted demanding for project spaces which on their turn leave the larger halls unoccupied. In such way learning spaces rest unused over an academic year, which is a waste of scarce facilities and money.

Due to the occupation and utilisation figures questions arose about how to make a more efficient use of present learning spaces and, moreover, how to facilitate mixed educational practices and interactive classes for collaborative arrangements. The challenge was to do this all without frustrating current education.

The usual way to cope with mixed practices for large cohorts is the use of multiple different teaching spaces at the same time, i.e. a lecture hall for introduction, central instruction or initial explanation and several classrooms for group work. In such cases two sorts of spaces are occupied at the same

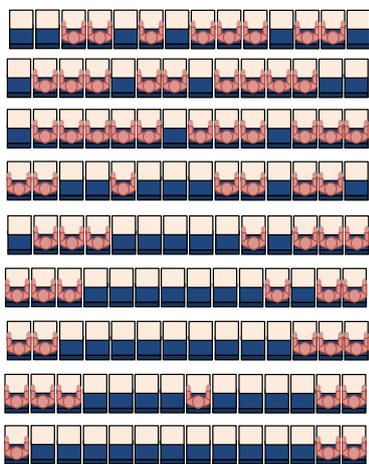


Figure 1: Side-sitters are common in Lecture Halls

time, meaning a maximum use of 50 percent. This is doable as long as there are enough lecture halls and classrooms available.

Unfortunately there are collateral issues such as time loss when moving to the other room and chaotic and noisy behaviour during the movements. Another issue is the distribution of students over the available seats. Students tend to sit at the row-side in order to leave in an easy way, as is indicated in Figure 1. Latecomers have to pass the side-sitters and cause delay, stumbling and noises of foldable tables and sometimes fallen objects.

A possible way to deal with the contradictory situation is to flexibilise classrooms through its furniture. That is done already for decades with the use of non-fixed tables and chairs on casters. The

problem with such furniture is that the lecturer has to arrange the classroom for the coming practice before class starts. For some occasions that is okay but over time it is just too much work. In practice, classroom furniture is seldom rearranged. Lecturers do not have the time to reorder the furniture between classes and support staff is no longer available to perform the task. Far too often, a flexible classroom is either flexible in name only or is left as a furniture mess [1]. As a result two separate sorts of teaching spaces remain: 1) frontal instruction spaces and 2) group work spaces.

Easy change of tables and seats from frontal instruction to group work vice versa and preventing messy arrangements in the classroom were challenges for an industrial design master assignment commissioned by Dr Piet van der Zanden at Delft University of technology. A first prototype was designed in 2010 by master student Timo van de Kreke in cooperation with manufacturer EromesMarko in the Netherlands (www.eromesmarko.nl). This prototype was converted into a null



series with two possible models for further evaluation. Meanwhile several improvements have been made for production series. These developments are described in more detail in the following sections.



Figure 2: Impression of Furniture that can be Revolved from Frontal Instruction mode to Group Work Mode

2 Development of Convertible Seating for Mixed Education Practices

In 2009 the industrial design master thesis assignment took off. It was commissioned as “Design and prototype a convertible seating for learning spaces where both lecturing and group work are part of the educational practice in consecutive ways” [7].

Directives were:

- Easy conversion from lecture mode to collaborative mode.
- Number of seats for group work, 4 to 6 dependent on design constraints.
- Space to put rucksack, bag or coat.
- Space to pass to facilitate easy student distribution and teacher accessibility.
- Two 230V power sockets per seat.
- One UTP wired network outlet per seat.
- Indication for occupied area in m² (not considered in this paper).
- Indication for production costs (not considered in this paper).

2.1 Exploring Market, Literature and Patents

Master student at the time Timo van de Kreke started with an exploratory study to outline an appropriate Master of Science investigation assignment, a steady problem definition, proper deliverables and planning for a sound analysis. Markets were explored for trends and for developments about foldable seats, chair-table combinations and rotary chairs, patents were looked over for usable concepts or to create a product without compromising property rights, and ergonomics was consulted for the target group design.

Nine manufacturers supplying the Dutch education market were studied, interviewed and weighed. Also the Dutch Association of School Manufacturers (NVS Nederlandse Vereniging van

Schoolmeubelfabrikanten) was contacted for additional information. Finally EromesMarko (www.eromesmarko.nl) was chosen as partner for the development of our convertible furniture.

Exploration made clear that there was only furniture available for large non-flexible lecture halls and for small flexible classrooms. There were neither patents nor furniture present for convertible seating as we had in mind.

2.2 Flexstool® Design

The exploring part of the study delivered insights in several important trends, such as efficiency, flexibility, downsizing the required space, open environment, decreasing lifetime and use of natural materials and shapes. Considerate investigation for the target group led us to our concept choice.

User requirements to be used in class were listed as laptop, note bloc, calculator, agenda, drawing paper, jacket, bag, lunch, coffee and soda can. Anthropometric characteristics for Dutch students were taken from DINED [8]. After that multiple standards were referenced, such as NEN-EN 527-1 Guidelines for Office Tables, NEN-EN 1729 Furniture for Educational Institutions, NEN-EN 2449 Ergonomic Criteria for Office Desks, NPR 1813 Ergonomic Principles for Workstations, NPR-CEN/TR 14699 Terminology for Office Furniture.

Several rotating, flipping, rolling and revolving ideas were explored and analysed with computer modelling. The selected model was further explored with strength calculations and rotation simulation. It was finalised aesthetically and presented to the promoters in spring 2010. Figure 3 shows the Flexstool® as semi-revolving furniture to accommodate both frontal Instruction and group work in one go.

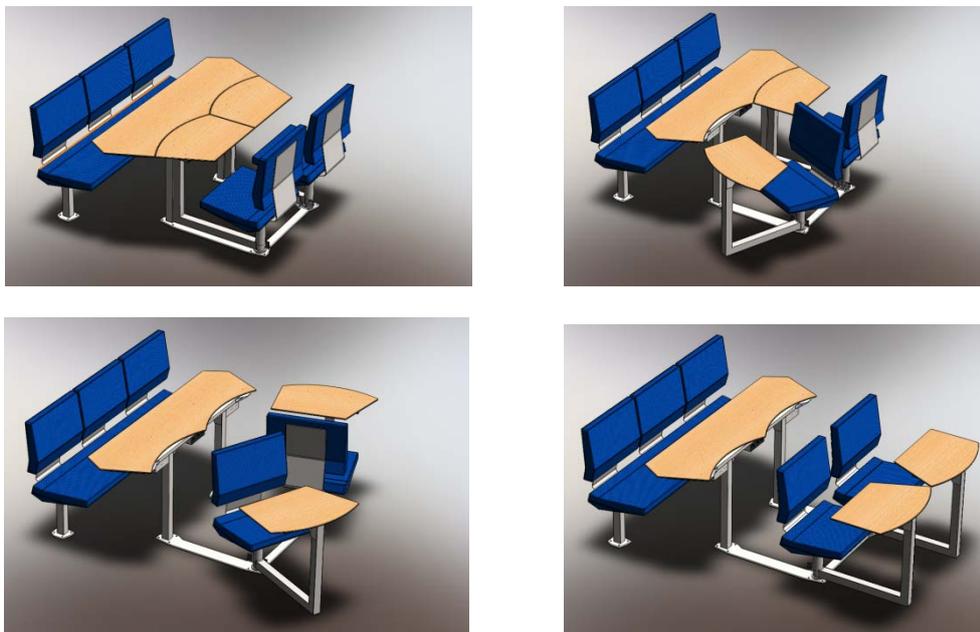


Figure 3: Flexstool® Design by Timo van de Kreke in 2010, depicted in several revolving positions

The Flexstool® consists of a framework with a fixed table and bench and two semi-revolving table-chair combinations. In the table frame four 230V power sockets and network outlets are available. Two persons take seat on the rotating chairs and three (or even four) persons sit on the bench. The revolving chairs are individual tables when in frontal position. In group mode the table tops merge into a large group table. The two revolving table-chair combinations have built-in network outlets and power sockets, with sufficient space for laptop and paper on its table top and enough

space for bags around the chair. The table-chair combinations have almost no movable parts, but tube rotation and dry-sliding bearings.

2.3 The Flexstool® Prototype

A complete working Flexstool® prototype was realised in cooperation with EromesMarko following the computer design. It was capable of facilitating lectures and group work or a combination of the two. Figure 4 demonstrates the Flexstool® prototype during a usability test.

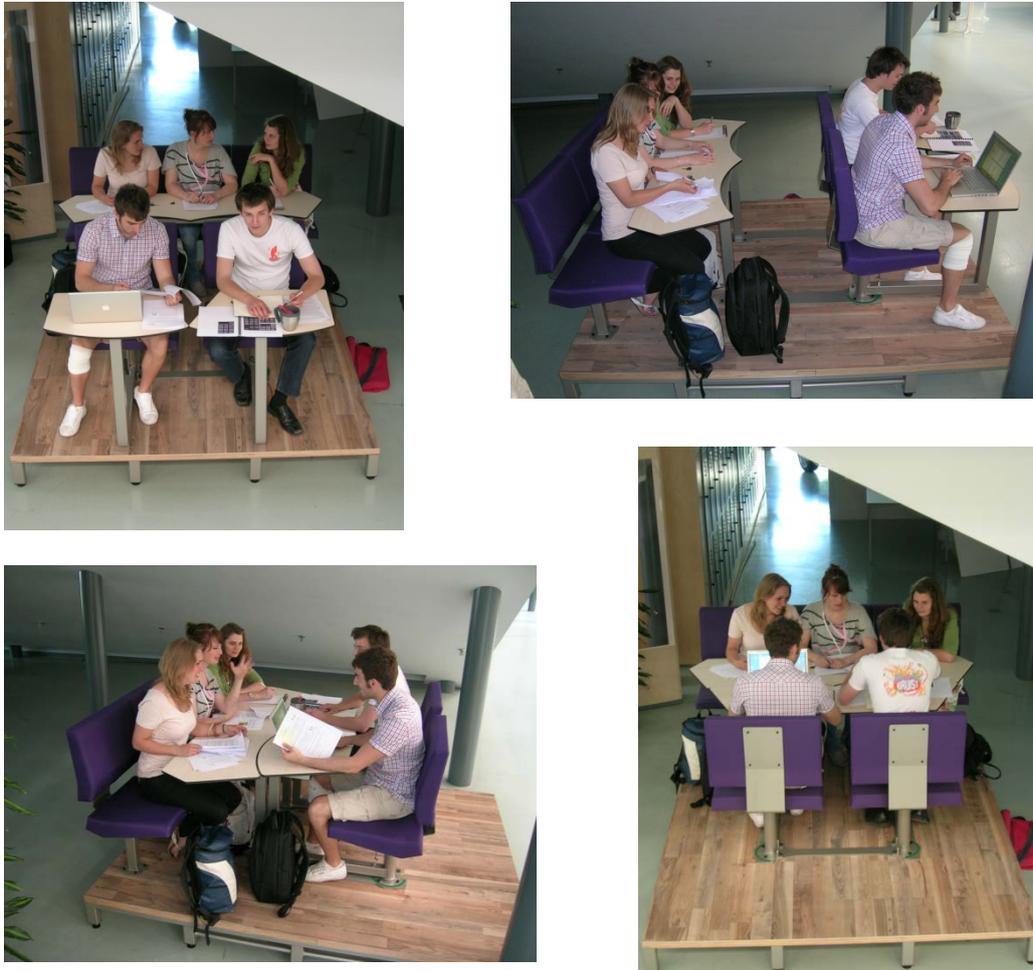


Figure 4: Usability Test of the Flexstool®, Depicted in Several Positions

The semi-revolving table-chair combinations can be rotated within seconds by students while seated. No more moving to another single practice classroom is required in case of mixed practices, which saves time and annoyance. The Flexstool® is developed with as less as possible moving elements to enhance durability.

2.4 User Test Results

In order to gain user-impressions of the Flexstool® a two-way approach was followed: 1) an unstructured one based on passerby's first reactions, and 2) a structured set-up for the usability test:

1. The Flexstool® prototype was situated in the faculty's entrance hall where anyone could make use of it. In a non-structured way students and staff were interviewed to obtain first-hand impressions while they took place at the furniture from their own free will, be it out of curiosity or verbal advertising.
2. A more structured set-up was the small-scale usability test with the target group [7]. Twenty students filled out questionnaires of which the results are listed in Table 1. The questions

addressed several ergonomic issues on a score scale from 1 (very bad) to 10 (excellent). Questions were posed in the form of “How do you think about ... “.

Table 1: Results of Flexstool® Usability Test (N = 20)

How do you think about ...	Average Score (1 = bad, 10 = excellent, N = 20)
[What is your age?]	[23.6 years of age]
[What is your length?]	[180.1 cm]
- Getting in	7.4
- Seat Height	7.8
- Seat Depth	7.8
- Leg Room	8.3
- Surface Size	7.3
- Surface Height	7.8
- Overall Space	7.7
- Buttock Support	8.1
- Back Support	7.8
- Luggage Space	6.4
- Leg Space New Position	8.6
- Comfort compared to common furniture	++
- Ease of action compared to common furniture	+

3 How Would the Flexstool® Do in Education Practices

The potential success of the 2010 Flexstool® prototype led us lobby for an education space where the Flexstool® could be tried out in real practice. After two years of acquisition five stakeholders were prepared to take a share in realising a flexible classroom. An opportunity came by with the Crowel Hall at the Industrial Design Engineering, which still had its original interior with forty years of age.

An intriguing question was how the prototype would look like to deliver the best results when used in real practice. Three plenary sessions with experts and target group representatives were organised to answer that question. Participants were educationalists, instructors, ergonomic adviser, AV-IT experts, union students, assembly specialist and manufacturer. It soon became clear that the final Flexstool® model for testing was hard to define. There was no consensus about a single model, hence two different models with two different connector assemblies were taken to be produced as null series:

- Blue bench model with smooth table top, see left arrangement in Figure 5a.
- Green chair model with table top cover for network outlet and power connector, see Figure 5b.



Figure 5: a) Blue Bench Model with Smooth Table Top and 5b) Green Chair Model with Connector Assembly in Table Top

A rectangular table top was chosen to have maximum workspace per individual. Next to that, a multi-tier floor was applied for better sightlines, as indicated in Figure 6. State-of-the-art audio-visual

equipment was installed in the Wim Crowel Hall also to facilitate multiple teaching practices. The interactive classroom became operational by the end of year 2012.

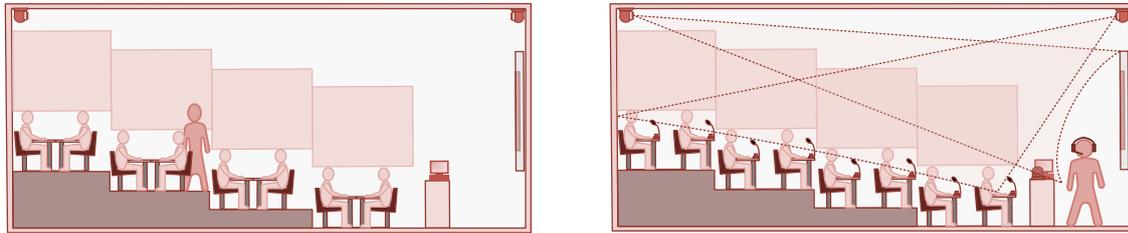


Figure 6: Flexstool® in Multi-tier Classroom for better Sightlines. Dry-erase Whiteboards on Wall for Break-Out Sessions

The Flexstool® furniture and AV-IT technology in the Crowel Hall are part of an ongoing study to facilitate new pedagogies. The evaluation after one-and-a-half years of use was five-fold: 1) technical improvements, 2) functional observations, 3) educational propositions, 4) lecturers' experiences and 5) students' experiences.

3.1 Technical Improvements

A first evaluation of the null series took place between manufacturer and university staff. Technical improvements were made within the production line as soon as they possibly could to provide every sold model in the first production year with the latest advancements. Some developments from factory were:

- a) Better tolerance settings for easy and aligned assembling.
- b) Welding moulds were improved for higher accuracy and stronger joints.
- c) Locking mechanism was changed; no handle anymore but supporting lock blocks (Figure 7).
- d) A more robust framework for the green chair backrest.
- e) Bearings from revolving table-chair combinations were improved.
- f) Table frame was strengthened.
- g) Table top fixation was strengthened and enhanced with extended slots.
- h) The use of wood as foundation floor, otherwise a very plain surface area.

3.2 Functional Observations

The functional observation lists several features and characteristics collected from educational support, audio-visual support and ICT support, next to the hearsay from teachers.

- a) The classroom still looks fresh and new. None of the quality materials is damaged, broken or otherways afflicted.
- b) Lateral pathways between the Flexstools® offer excellent accessibility for the instructor to reach every student group.
- c) Turning and locking the table-chair combination with lock blocks is easily done within seconds. No instruction is needed.
- d) Sometimes locking needs another try, which is not experienced as problem.



Figure 7: Lock Block to Fix and Support the Table-Chair Combination in Frontal Mode and in Group Mode

- e) Blue bench models offer an extra seat when classes are crowded or offer lecturers to sit by in case of dedicated group instruction.
- f) Blue bench models are luxurious and first choice to take seat. However, long and large persons prefer the green chair model because of larger space between tabletop and backrest.
- g) Table pegs, as shown in Figure 8, contain an opening to lock laptops with a Kensington security cable. Students have brought forward the idea for such punched pegs.

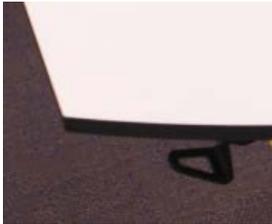


Figure 8: Table Peg with Opening for Kensington Security Cable

- h) Power sockets are used regularly to charge mobile phone and laptop. However, the green table top connector assembly is an expensive investment because the wiring runs right through the framework of the revolving table-chair combination, see Figure 9a. An extra socket instead in the table frame is easy accessible and offers table-chair sitters enough possibilities to charge their tools, see Figure 9b. In such way this expensive and failure sensitive feature may be left out.



Figure 9: a) Connector Assembly in the Green Model's Tabletop, and b) Connector Assembly in the Table's Frame

- i) Network outlets were hardly used, but its provision for future use is foreseen with downloading software from the private university cloud.
- j) Every Flexstool® centre chair is equipped with a microphone connector for conferencing. It has not been used to date, practices are yet to come.
- k) The table-chair combinations are sometimes used in unlocked situations, e.g. when students want to follow the instructor's talk from another Flexstool® position in class. In such case the table-chair combination is not supported by the lock block and its bearings stressed. Still, material capabilities are oversized and no problems occurred.
- l) Sometimes, the small slit space between table tops causes annoying contact sounds when table tops hit each other in merged position during the rotation act. Maybe bump rubbers are helpful or a larger split.
- m) In the very first week of use several rubber parts were removed from connector assemblies in the green furniture. It does not happen anymore.
- n) Connector assembly in the green furniture is accessed through its tabletop cover. The cover contains a fine slit around it where sometimes the pen is pushed through paper during the

writing. Experience taught us that the table top access is expensive and not convenient. It has no added value.

- o) In the beginning, locking the table-chair combination was done with a handle, see Figure 10a. Today lock blocks do the work, see Figure 7. However, the remaining parts of the earlier blocking system in our null series start to make screeching noises.
- p) The stainless steel diamond plate on table-chair combinations protects the frame from wear and tear, see Figure 10b. They still look quite new despite regular occupation of the Crowel Hall.

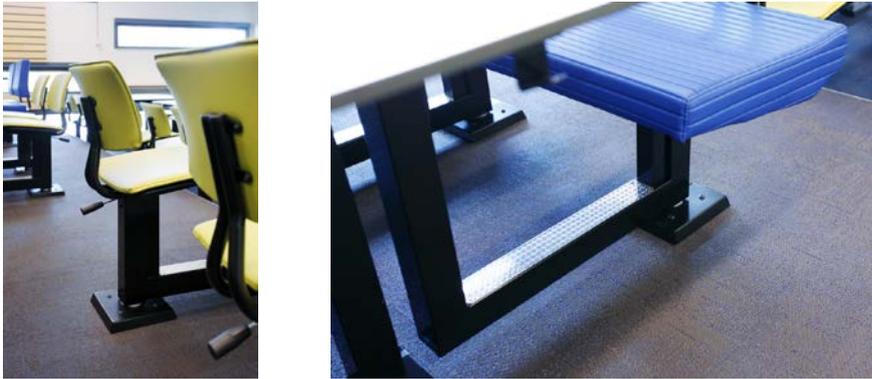


Figure 10: a) Early Version with Handle to Lock Position, and b) Stainles Diamond Plate to Protect Table-Chair Combination

- q) Blue seats from two different benches are distorted. Probably some great forces were placed upon the seats' corners. Meanwhile the frame is strengthened.
- r) The blue luxurious model forces students to sit straight from which an active attitude seems to come forth. Two people were very pleased with the blue model referring to their back troubles.

3.3 Educational propositions

- a) The Flexstool® is very suitable for interactive classes, i.e. the combination of frontal instruction and group assignments. Peer-learning is increasingly becoming important within higher education. Next, flipped classrooms, where students prepare themselves with online materials before joining class, will take a larger part of formal contact hours.
- b) The Wim Crowel Hall is set up breadthwise instead of lengthwise. It provides everyone with short sightlines and better visual contact between lecturer and students.
- c) The Wim Crowel Hall is very popular with lecturers and students, especially for thesis defences. Instructors like the Crowel Hall very much and some want to instruct permanently in such a hall.
- d) Lecturers do sit by on the blue bench when specific coaching or instruction is given.
- e) Occupancy of the Wim Crowel Hall is about 90 percent of which 20 percent is for research purposes.
- f) Whiteboards for break-out sessions are hardly used, although most lecturers and students would not like them to be removed.
- g) Videoconference with partner institutions will increase.

3.4 Lecturers' Experiences

An online survey was held amongst the lecturers who made use of the Wim Crowel Hall and adjoining design classrooms in last academic year. A total of 19 lecturers responded. Only 6 of them responded on questions that aimed at the revolving furniture although at least 12 instructors made use of the Flexstool® within their course.

- a) Two out of six had a permanent use of the Flexstool® for their education practice. Another 3 think that they will apply it soon within their pedagogy.

- b) Group sizes for interactive classes vary from 50 to 65 participants.
- c) Four lecturers valued the furniture's possibility to revolve front chairs from forward position to group situation and vice versa with good and two lecturers even with excellent.
- d) Five out of 6 experienced the rotation of the table-chair combination from okay to good.
- e) The white lock block had not hindered any of the lecturers.
- f) Five out of 6 lecturers experienced the group mode situation for students to cooperate and to discuss as good.



Figure 11: a) Students work together in Group Mode, and b) act attentively during Instruction Mode

- g) The 6 lecturers do not really have preference for the green or blue furniture. It is the revolving feature that counts.
- h) One of the lecturers took the opportunity to sit by on the blue furniture bench when coaching student groups.
- i) One lecturer answered that the breadthwise arrangement of the Crowel Hall for shorter sightlines is okay, 3 think it is good and 2 answered excellent.
- j) Three out of 6 answered that students in the Crowel Hall are more motivated due to the Crowel Hall's arrangement. Two answered maybe and one lecturer responded negative.
- k) Three of the lecturers responded that the accessibility to every group in the classroom is good via the parallel pathways. Two answered okay and one negative.

The six lecturers responded that the Wim Crowel Hall in general is a very nice hall despite its test arrangement. It is especially loved for presentations, guest lecturers, inaugural speeches and interactive settings. Also instructors of the Graduate School (not addresses by this survey) love the Wim Crowel Hall since now they can apply a mix of practices.

3.5 Students' Experiences

The online survey for lecturers was combined with questions for students who have been visiting the Wim Crowel Hall during classes. A total of 44 students responded to the questionnaire. Twenty of them made use of the Flexstool®.

The DINED anthropometric database was taken as reference for the design of the Flexstool®. The students' average length was 178.2 cm ± 11.2 cm, their average weight 71.2 kg ± 11.8 kg.

- a) When comparing the green furniture's to common classroom furniture, 5 out of 20 students replied okay, 10 answered good and 2 excellent.
- b) When comparing the blue furniture's to common classroom furniture, 2 out of 20 students replied okay, 10 answered good and 5 excellent.
- c) Three students have sit with four persons on the blue bench instead of three.
- d) Students clearly prefer the blue furniture. None of the students preferred the green one.
- e) Nine out of 20 students prefer sitting in the middle for best classroom experience and blend in with the crowd.

- f) Eight students prefer sitting at the back so that they can take their laptop or phone without anyone being interrupted.
- g) Most students have rotated the chair from frontal position to group position and vice versa. Four students valued the possibility with okay, 7 with good and 7 with excellent. However, the ease rotation while seated was rated good by only 9 students, 3 rated negative and 4 with okay. It is unknown who used the early handle version and who the lock block version.
- h) The lock block bothered only two students. No additional comments are available.
- i) The interstice (in between space) of the table tops with the furniture in group position was negatively experienced by 3 students only when writing large A1-sized paper. In other situations there was no complaint.
- j) Students experienced cooperation and discussion in group mode very positively. Two of them answered okay, 11 good and 3 excellent.
- k) Unfortunately only 1 out of 20 students have made use of the table peg/hook to place a bag or rucksack. Also only 1 student used the peg hole to secure his laptop with a safety-cable.
- l) Students appreciate the power sockets over network outlets. Sixteen out of 20 used power for their tools while only 2 students used the wired network. Most of them use wireless.
- m) The cover in the green furniture's table top gain easy access to the connector assembly but is not popular due to its slit. Moreover, accessibility of the network and power connectors in the blue furniture table's frame is easy enough for students.
- n) The Wim Crowel Hall's breadthwise arrangement is very positively experienced by the students. Only two of them thought it was not okay. Also the seat accessibility was valued positively. In general, students think that the Wim Crowel Hall is a very nice hall.

4 Flexstool® Production Series

Testing the revolving furniture in real-time education practice will continue and data about its uses collected. At the same time the Flexstool® production series is offered to market.

Unique selling points are:

- The Flexstool® as new revolving furniture converts an instruction classroom into a project space within seconds. No extra time from lecturer or support staff is needed; students easily rotate the table-chair combinations from frontal mode to group mode.



Figure 12: Colourful Impressions of Flexstool® Production Models

- A multifunctional classroom with Flexstool® furniture facilitates multiple education practices. In such way an education space is used more efficiently. Estimated occupancy improvement is from about 45 percent up to 85 percent, reducing facility costs, electricity, heating, etc.
- Flexstool® furniture is attractive for guest lecturers and inaugural activities. The regarded education space may be exploited more efficiently.

- The Flexstool® is comfortable. Students sit straight which leads automatically to active attitudes in class.
- Compared to furniture in lecture halls the Flexstool® has very steady table tops, seats are easily accessible, there are no collateral issues, such as noises from foldable tables and side-sitters.
- Table tops have enough individual working space in frontal instruction mode. In group mode the table tops merge into one large project table.
- Network outlets and power sockets are arranged in the table frames.
- The ergonomic and functional design is cheap in maintenance and easy to clean.
- The Flexstool® is developed in partnership with Delft University of Technology (www.tudelft.nl) and EromesMarko (www.eromesmarko.nl).

5 Epilogue

Colleagues from faculty and many external and international higher education institutions are enthusiastic about this multifunctional furniture for mixed practices. The Flexstool® bridges the gap between lecture halls and project spaces creating a third category of teaching space.

Compared to lecture halls a reduced seat capacity with a maximum of about 60 to 70 percent is feasible. Occupancy and utilisation, on the other hand, will lead to much higher figures than those of lecture halls.

Moreover, when the total costs of ownership (TCO) is considered for modern learning spaces, only then an objective calculation can be made. Maintenance and exploitation costs are energy costs, heating, spatial and window cleaning, facility services, purchase of audiovisual and IT equipment with 5 years lifetime, preventive maintenance, corrective maintenance, security, opening hours, purchase of furniture with 10 years lifetime, repairs, support, network and daily materials. Early calculation shows a TCO between € 250,- and € 500,- per square meter of education space. It is worth to set up calculation models to better plan investments for different sorts of learning spaces.

Compared to project spaces the flexibility is limited because the Flexstool® facilitates only two modes: frontal instruction and group assignments. Non-fixed tables can be arranged in any order, however, such flexibility leads to non-flexibility because work to rearrange is just too much for the lecturer. As a consequence almost no reordering takes place at all in project spaces.

In the end, the Flexstool® unburdens the lecturer from heavy and time-consuming arrangement efforts in class. Mixed education practices will be easier to conduct with the Flexstool®, which creates opportunities for pedagogical change in higher education.

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