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A Survey on Daylighting Education in Italian Universities. Knowledge of Standards, Metrics and Simulation Tools

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Abstract

Daylighting is a strategic topic to achieve sustainable buildings, so it is more and more imperative that it is implemented in architecture curricula to prepare a new generation of daylighting-oriented practitioners. In this frame, the DAYKE project (Daylight Knowledge in Europe) was set up to explore the level of knowledge about daylighting among European professionals and students. DAYKE-Europe was replicated as DAYKE-Italy to study the knowledge of daylight standards, metrics and software among Italian architecture students, and to compare it to that observed within DAYKE-Europe. A sample of 542 questionnaires were collected in five universities. Primary outcomes were: (i) a general low level of knowledge on daylighting was observed; the most cited metrics were the average daylight factor and the geometrical window-to-floor ratio, while climate-based daylight metrics were rarely mentioned; (ii) master science M.Sc. students reported more knowledge on daylight metrics and regulations than bachelor B.Sc. students, while the implementation of daylight metrics and strategies in projects was mainly deficient among B.Sc. students; (iii) compared to European students (DAYKE-Europe), Italian students showed a higher knowledge of daylight metrics and software (especially as for M.Sc. students), while the opposite was observed for standards, regulations and protocols. Based on the results, a reconsideration of daylight education in architecture curricula is recommended.

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1. Introduction

Daylighting is acknowledged as a strategic topic to achieve sustainable buildings, as it plays a significant role in three, interconnected, crucial aspects:

1. energy saving, through an optimisation of the integration between daylighting and electric lighting and of the control of solar gains for reduced energy use for lighting, heating, and cooling; the energy-saving aspects concerned with appropriate integration of daylighting and electric lighting have received particular attention over the last 15 years, as part of an integrated approach to predict and calculate the total energy consumption of a building [1-2]
2. comfort for the occupants of an indoor space, in terms of illuminance over the workplane and luminance distribution inside users field of views, for an optimized, glare-free visual performance [3-4]
3. health through the non-visual effects of light that impact on the circadian rhythm of humans [5-8]; factors such as light intensity and spectral distribution, duration and timing affect

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sleep quality, sleepiness and vitality, alertness and productivity for the occupants of a space.

It appears evident that a conscious daylighting design needs to be addressed through a multidisciplinary approach, which includes expertise from several areas: cognitive, psychological, and physiological. As a result, building practitioners need to cope with a quite complex mix of metrics: *daylight* metrics, both static such as the average daylight (average daylight factor DF_m and climate-based (Daylight Autonomy DA [9], spatial Daylight Autonomy $sDA_{300,50\%}$ [10], Annual Sunlight Exposure $ASE_{1000,250}$ [10]: Useful Daylight Illuminance UDI [11], and Daylight Glare Probability DGP [12]), *circadian* metrics (circadian stimulus CS, circadian action factor CAF, equivalent melanopic lux EML [6-8]); and *energy-related* metrics (lighting energy numerical indicator LENI [1]). Besides, they need to comply with many different standards, regulations, and protocols. For instance, the European Standard EN 17037:2018, 'Daylighting in buildings' [13], issued by the Comité Européen de Normalisation CEN. [13].

A few studies have investigated to what extent daylighting metrics and criteria are known and used in the design practice. In 2006 and 2008, Reinhart & Fitz [14] and Galasiu & Reinhart [15] carried out two studies with over 360 building practitioners involved, to investigate which tools were currently used for daylighting analyses in the design practice. "Experience from previous work" and "rules-of-thumb" were the daylight prediction tools on which design practitioners most commonly rely during the schematic design phase, postponing the use of advanced, dynamic simulation tools until a detailed design stage. More recently, Brambilla carried out [16] a survey among researchers and professionals who were using the CBDM approach in their projects, to investigate different aspects such as: (i) for what type of projects they used CBDM (office and educational buildings were the most mentioned); (ii) which CBDM metrics they used (DA and UDI resulted the most used metrics, while DGP, sDA and ASE were used less frequently); and (iii) whether they used the CBDM approach to comply with a standard or protocol (LEED v4.1 [17] protocol was the most mentioned document).

Besides, it is also worth stressing that recently, in an era when both the CBDM metrics and the use of optimized devices for the integration between daylighting and electric lighting have become available for energy saving purposes (through occupancy and photodimming sensors), some studies outlined that existing general knowledge about lighting retrofit is currently very limited and there is a significant lack of information concerning the actual energy performance of lighting systems as well as of lighting controls [18-20].

Overall, a substantially low level of knowledge about daylighting issues among professionals, building designers and practitioners seems to emerge. Within this frame, these paper reports findings from the DAYKE (DAYlight Knowledge in Europe) research: DAYKE-Europe was carried out in a first stage in some European architecture faculties to investigate how daylighting is taught at a university level, where building practitioners are educated and trained to implement conscious daylighting strategies into their later professional design activities [21-22].

DAYKE-Europe was methodologically replicated and applied to an Italian partnership (DAYKE-Italy), using the same ad-hoc survey that was developed within DAYKE-Europe. The present paper presents results that were obtained within the DAYKE-Italy project. The DAYKE questionnaire was distributed among both Bachelor of Science (B.Sc.) and Master of Science (M.Sc.) students in five universities across the Italian territory, which led to collecting 542 questionnaires for analyses.

2. Objectives of the study

The main goal of the study was to explore how daylighting is taught and learnt in a sample of architecture universities in Italy. As part of this, the study aimed at investigating the gap between latest advances that have been made in daylighting research, which led to new metrics, standards and regulations, and the education on daylighting in schools of architecture, where the next generation of building practitioners and professionals are trained. For this purpose, an ad-hoc survey was used to interrogate the students about their level of knowledge on the following three main topics:

- Knowledge about daylight metrics/indicators, investigating both the knowledge at a theoretical level and the application in design courses (implementation into architecture projects).
- Knowledge about daylighting simulation tools.
- Knowledge about daylighting standards, regulations, and protocols (both European ad Italian).

Such investigation was carried out in two phases:

1. Analysis of the outcome at an Italian level, by analyzing the responses provided by the 542 questionnaires collected within DAYKE-Italy.
2. Comparison of average trends emerged from DAYKE-Italy to average trends emerged from DAYKE-Europe.

2.1 Research questions

Consistently with the objectives of the study, the following Research Questions (RQ) were defined about the level of knowledge expressed by the students:

RQ1: What kind of knowledge do Italian students have about daylight metrics, regulations, and simulation tools?

RQ2: Does the knowledge vary between Italian B.Sc. and M.Sc. students?

RQ3: Are results collected through DAYKE-Italy comparable to results collected through DAYKE-Europe [21-22]?

3. Method: the DAYKE-Italy project

3.1 Replication of DAYKE-Europe into DAYKE-Italy

The idea to methodologically replicate DAYKE-Europe as DAYKE-Italy lies on a deep revision process that architecture universities in Italy have been addressing over the last couple of years to implement new educational curricula in line with the latest goals set by the United Nations for sustainable and inclusive development. For instance, 'Envision 2030 - goal 4: quality education' sets, among others, the following target 4.7: "*By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles*" [23]. Alternatively, 'goal 11: Sustainable Cities and Communities' sets, among others, the following requirement: "*Support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening*

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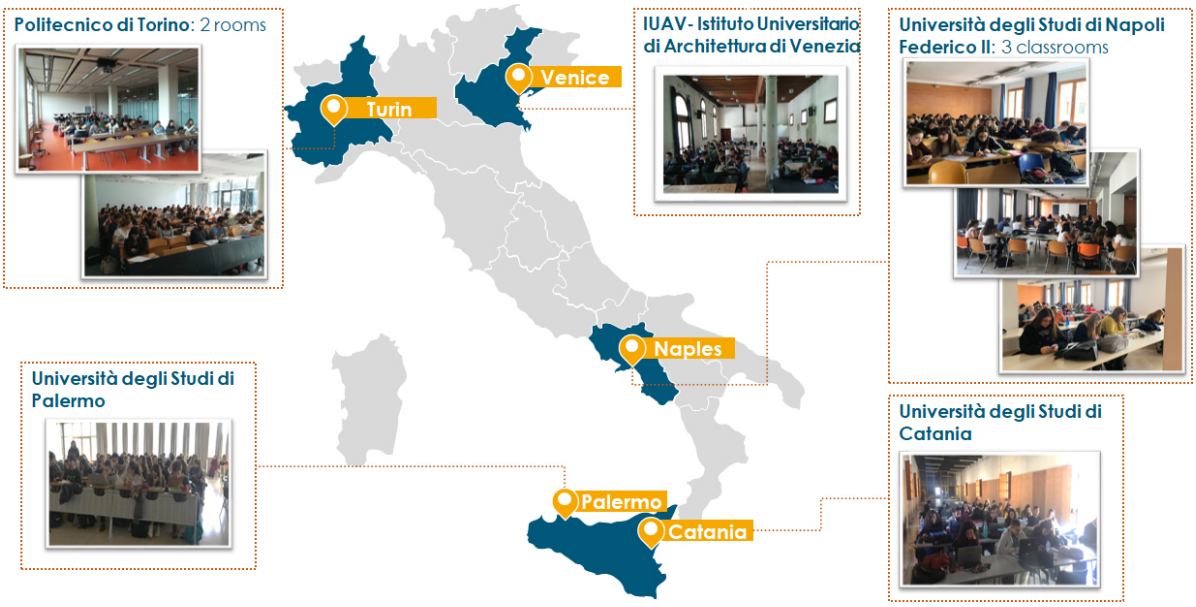

Fig. 1. Architecture universities that took part in DAYKE-Italy survey.

national and regional development planning", and "*substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement*" [24].

In this frame, 'daylighting' was identified as one of the driving vectors, due to its impact on comfort, health for the occupants and energy saving-related issues, as well as and on aesthetical, formal, and technological aspects of buildings and cities of the future. Considering the strategic role played by daylighting, it was decided to replicate the DAYKE survey across the Italian territory, through the DAYKE-Italy project, to assess the general level of knowledge as expressed by a sample of students in architecture and to compare it to the average level of knowledge that was observed in Europe (results from the earlier DAYKE-Europe). The goal was to understand the magnitude of the knowledge about daylighting in Italian universities and if this was similar, higher, or lower than the average knowledge expressed on daylighting issues by a sample of European students in the same field (architecture).

The DAYKE survey relies on three primary areas of investigation: (i) *perception* of a daylit space (university classrooms in schools of architecture), in terms of visual performance and comfort perceived by the occupants; (ii) *preferences* about daylighting; and (iii) *knowledge* about daylighting, in terms of metrics, simulation tools and standards/regulations. They were set to account for the different areas (cognitive, perceptive, physio-psychological) that are concerned with a daylit space.

In this paper, results from DAYKE-Italy about the *knowledge* section are presented. The ad-hoc questionnaire built for DAYKE-Europe was distributed among both B.Sc. and M.Sc. students in five universities across the Italian territory (Turin and Venice in northern Italy, Naples in central Italy, and Catania and Palermo in southern Italy), as shown in Fig. 1. Specific questions were addressed to students to investigate their knowledge about daylighting, with regard to both theoretical aspects (in terms of daylighting metrics, software, standards), and practical use of daylighting in design projects (implementation into architectural practice). Eight classrooms were considered in total, and a sample of 542 questionnaires was collected and processed through two different campaigns: the first one was conducted in April-May-June 2019 ('spring session'), the second one in November-December 2019 and January 2020 ('fall-winter session'). The 5 universities and the 8 classrooms were selected to have a sample able to represent several, different scenarios in terms of daylight quantity and distribution across the room, due to different climate and architectural features (orientation, window area, room depth). Particular attention was paid to create a mix of classrooms located in new or in historical buildings, conceived for other functions and later transformed into learning spaces.

3.2 The DAYKE questionnaire: questions on 'knowledge about daylighting'

The DAYKE questionnaire is an ad-hoc instrument developed based on previous questionnaires available in the literature that investigated different aspects of daylighting in educational [25-26], office [27], residential [28] and healthcare [29] buildings. The online mode was chosen after carrying out the first survey within DAYKE [21]: a paper questionnaire was used at first, but then it was decided to use an online platform (Google Forms) to handle the collection and management of a very large number of responses. Besides, some questions were also modified, as they were not easy to cope with in the presence of massive data (f.i. questions that used open-ended answers).

The DAYKE questionnaire that was developed consists of five sections: (1) environmental impressions; (2) perception; (3) preferences; (4) knowledge; and (5) socio-demographic information. The different sections dealt with aspects related to psychology (impression and perception), arts (preferences) and engineering (knowledge), considering daylighting as a multifaceted topic, deserving attention from a variety of disciplines [4]. Different types of questions were used for the various sections of the DAYKE questionnaire: for *environmental*

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impression, which collects a set of subjective data, multiple-choice questions and 5-point bipolar scales with semantic descriptors for each point were used; the section *perception* uses 5-point unipolar and bipolar scales with semantic descriptors for each point; the section *preferences* uses multiple-answer questions created to investigate preferences towards different types of (day)lighting conditions and daylighting use in buildings, as well as beliefs and cultural issues; the final section, *personal information*, includes participants' socio-demographic (e.g. gender, age) and daylighting education information, including daylighting design training. More detail on the survey can be found in [22].

The section *knowledge*, due to the inherent characteristics of the items addressed, uses 'yes/no' questions to determine which share of respondents report knowing daylight metrics, simulation tools and standards. 'Yes/no' questions are then integrated with open-answer questions, where the respondents can specify which metric, standard, and software they are familiar with.

In more detail, the section accounts six items:

- Item 1: Do respondents know any daylighting metric/indicator? If so, which ones?
- Item 2: Have respondents participated in any design project (design studios, ateliers, laboratories) where daylight metric/indicator were used? If so, which metrics did they use?
- Item 3: Have respondents used any daylighting software? If so, which one?
- Items 4-5-6: Do respondents know any daylighting standards/regulations on daylighting? If so, which ones? This item was split into three different sub-items, concerned with European standards/regulations (Item 4), national standards/regulations (Item 5), or 'other' regulations (related to building, or energy efficiency), not specifically concerned on daylighting but which addressed issues such as energy, daylighting, or solar gains, or shading (Item 6).

It was decided not to investigate the knowledge about circadian lighting and metrics, as this topic is still not mature enough to be implemented in a consolidated and widely accepted body of regulations. The WELL protocol [30] is the first and only document that introduced requirements in terms of circadian lighting (through the equivalent melanopic lux EML), but it is still too soon to expect circadian lighting to be taught among students. The investigation was therefore focused on daylight and energy-related metrics, software, and regulations.

Above questions of section 'knowledge' were integrated with some questions that were introduced in the last section of the questionnaire ('*personal information*'), namely:

- Which academic degree are respondents attending (Bachelor Science or Master Science)?
- Have any of the courses that respondents have attended during their curriculum addressed daylighting analysis and/or calculations? Were they theoretical courses or applicative design studios/laboratories?
- Have respondents attended extra-curricular lectures (seminars, webinars, workshops) on daylighting subjects?

At the beginning of each session, participants were briefed about the rating instructions and meaning of the terms used in the questionnaire (i.e. metrics, regulation, etc.).

3.3 Data analysis

To address the Research Questions defined in Section 2.1, descriptive statistics were computed for each variable of interest: frequencies and percentages of correct, incorrect and false-positive answers (FP, i.e. a respondent reported to know a metric, to have applied it in a project, to have used a simulation tool and to know the three types of regulations but then he/she was not able to name any of them) were computed, for both B.Sc. students and M.Sc. students. Moreover, to answer RQ2, the performance of B.Sc. and M.Sc. students in Italy were compared through a chi-square (χ^2) test to check for any significant differences. A different series of chi-square (χ^2) tests was then calculated to answer RQ3, that is to investigate the possible differences between Italian and European participants in general (DAYKE-Italy vs. DAYKE-Europe) and between B.Sc. and M.Sc. students in Italy and in Europe, by comparing:

- Knowledge of each of the six knowledge items considered in all Italian students (DAYKE-Italy) vs. all European students (DAYKE-Europe).
- Knowledge of each of the six knowledge items considered in B.Sc. students in Italy (DAYKE-Italy) vs. B.Sc. students in Europe (DAYKE-Europe).
- Knowledge of each of the six knowledge items considered in M.Sc. students in Italy (DAYKE-Italy) vs. M.Sc. students in Europe (DAYKE-Europe).

Furthermore, in order to compare the 'overall knowledge performance' between B.Sc. and M Sc. students in Italy and in Europe, an overall knowledge score for each participant was computed as the sum of the correct responses given to the six knowledge items (the score could therefore range between 0 and 6). This score was then used as dependent variable in a two-way Analysis of Variance (ANOVA) in which Degree curriculum (B.Sc. vs. M.Sc.) and Nationality (Italian vs. Europe) were used as independent variables. P-values <.05 were considered significant. Statistical analyses were performed using SPSS software v26.

4. Results

Figure 2 summarises some of the main socio-demographic characteristics of the sample of 542 questionnaires that were collected within DAYKE-Italy. As shown in the figure, a prevalence of female students was observed compared to male students (61% vs. 39%). The students ranged from 18 years old to 34 years old, with a prevalence of students between 20 and 23 years old (as one could expect), which means that the sample was well representative of students enrolled in both a B.Sc. (42%) or in a M.Sc. (58%) curriculum. In Turin, the students were equally subdivided between B.Sc. and M.Sc., while a predominance of M.Sc. students was observed in Naples (73%) and Palermo (90%), and the opposite applied to Catania (10%). In Venice, all the students who participated in the survey were attending a M.Sc. curriculum.

As a whole, 52.4% of students within DAYKE-Italy reported to have previously attended at least one course during their curriculum that addressed daylighting analyses and/or calculations, while a minor share (5.1%) reported to have attended some extra-curricular lectures (seminars, webinars, workshops) on daylighting subjects. These shares were comparable with what observed within DAYKE-Europe, where 54.1% and 5.2% of

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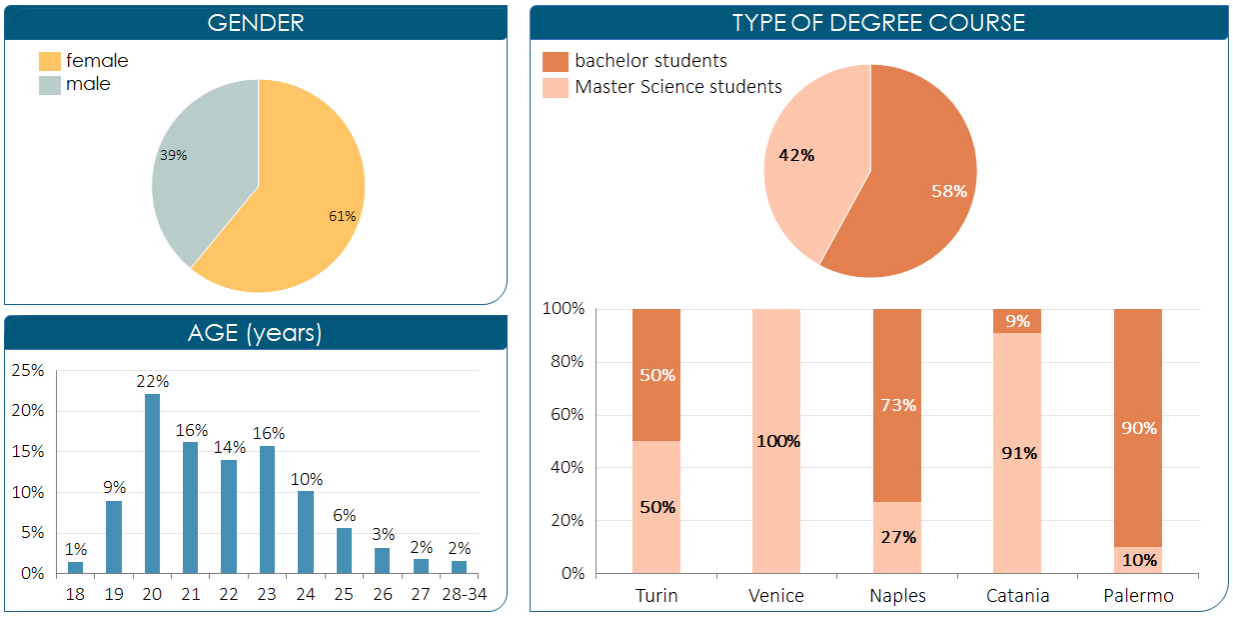

Fig. 2. Summary of socio-demographic characteristics of the sample and subdivision into B.Sc. and M.Sc. students.

European students attended curricular or extracurricular courses on daylighting, respectively.

4.1 RQ1: what kind of knowledge do students have about daylighting metrics, regulations, and simulation tools within DAYKE-Italy?

Figure 3 shows the frequency of positive answers collected within DAYKE-Italy, i.e. the percentage of students who responded 'yes' to questions on daylighting knowledge (f.i. "*Do you know any daylight metric/indicator?*", or "*Have you ever used software for daylighting modelling and calculations?*"). Special attention was paid to 'false-positive' responses (FP), which may act as a bias in interpreting the results obtained. Two types of FP responses were identified:

1. students who reported 'yes' to a certain binary question on daylighting (f.i. "*Do you know any daylight metric/indicator?*"), but then left a blank space in the following open question ("*if so, which one?*"); these FP responses were labelled "missing responses"
2. students who reported 'yes' to a certain binary question on daylighting (f.i. "*Do you know any daylight metric/indicator?*"), but then provided an inconsistent answer, mentioning for instance a standard, a wrong unit, or a thermal metric instead of a proper daylight metric; these FP responses were labelled "inconsistent responses".

Consequently, the number of '*positive responses*' was decreased after removing the FP. In this regard, Fig. 3 shows the results after removing the FP '*missing responses*' (while 'inconsistent responses' are discussed in Sections 4.1.1-4.1.2-4.1.3). Based on the information displayed in the Figure, the following considerations can be drawn:

- FP values ranged from a minimum value of 4.9% for 'daylight metrics' up to 31.1% for 'national standards', which means that 31.1% of students who reported to know at least one national standard could not specify any standard at the following question ("is so, which one?"), leaving the question unanswered (blank string).
- As a general trend, the knowledge about the various daylighting aspects investigated seems quite low, particularly for 'standards' (the maximum percentage of positive answers was 8.1%, found about national standards), but also with regard to the participation in 'projects' (only 13.8% of students answered 'yes' to this question).
- The higher knowledge was reported about 'metrics' (35.6%) and 'software' (25.1%): over one-third of the respondents reported to know at least one daylight metric, while one fourth reported to have used at least one simulation tool for daylighting analyses.
- A quite lower rate of students who participated in at least one project where daylight metrics were used was observed, compared to the rate of positive answers about knowledge of metrics; this may suggest that daylight metrics are mainly learnt in theoretical courses, but their application/implementation in design courses (studios and laboratories) remains to a lower extent.
- The rate of students who have used a daylighting simulation tool is almost twice the rate of students who participated in projects that involved daylighting analysis; this may be due to the fact that the respondents referred to software for architectural modelling, which also allows some daylighting modelling to be performed.

4.1.1. Knowledge on daylight metrics and their application in projects (design studios or laboratories)

As far as the theoretical knowledge on daylight metrics is concerned, 35.6% of the sample of respondents reported to know at least one of them. Figure 4 shows the metrics that were mentioned by the respondents, after removing the FP 'missing answers'.

As shown in the Figure, the average daylight factor DF_m and the window-to-floor-ratio WFR were the most cited metrics (60.7%

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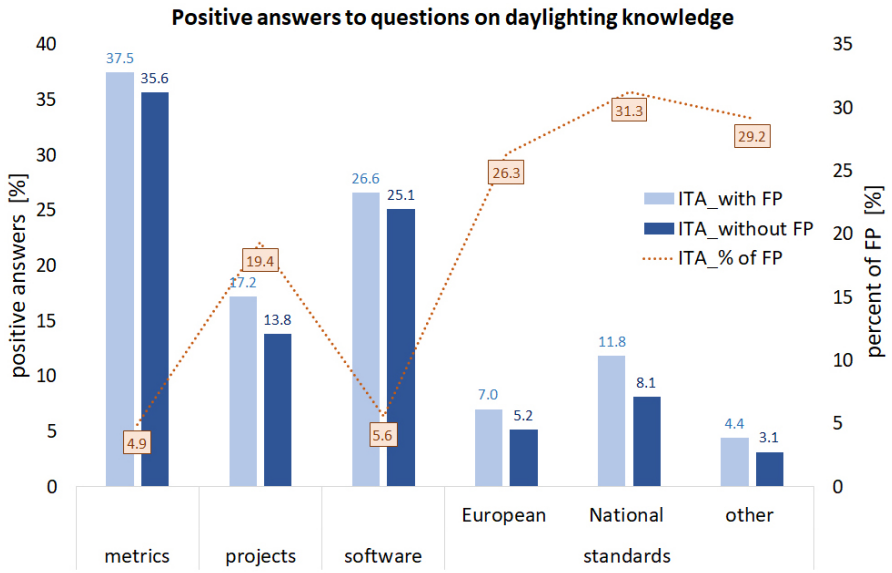

Fig. 3. Percent of positive answers (i.e. respondents who declared to know at least one daylight metric, to have participated in a project using a daylight metric, to know at least one daylighting software and standards/regulations on daylighting). For each aspect of knowledge, both the total positive answers and the 'effective' positive answers (deducing FP responses) are shown. The secondary vertical axis shows the percentage of FP.

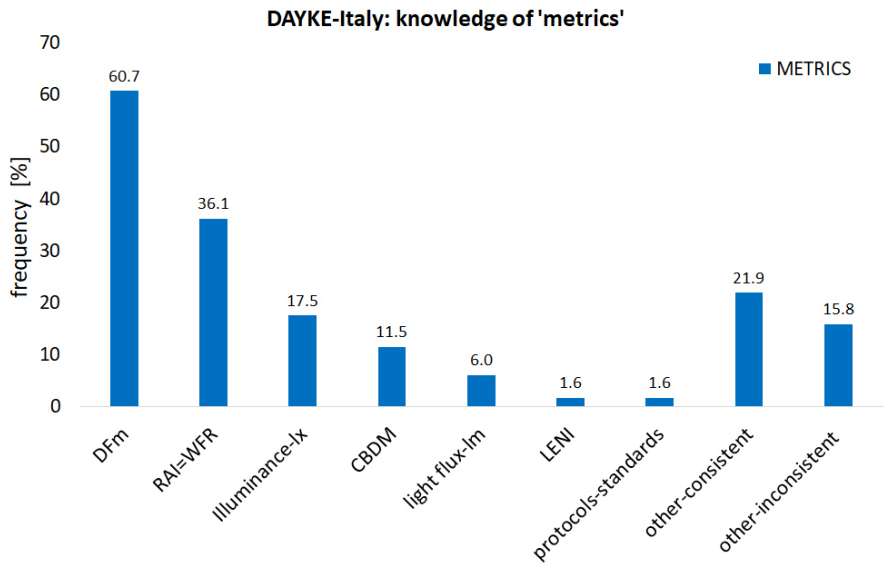

Fig. 4. List of daylight metrics which were mentioned by the respondents. NOTE: the label '*other-consistent*' includes a number of photometric quantities: luminous intensity and candela, Color Rendering Index and Correlated Color Temperature, luminance; the label '*other-inconsistent*' includes: heat, comfort, wavelength, radiation, refraction, software, sun path, measurement instruments, transmittance, Waldram.

and 36.1%, respectively). Other daylight metrics cited were 'illuminance' and the advanced CBDM metrics (17.5% and 11.5%, respectively). These latter were cited in Turin and Venice only, but it should be noticed that they were not cited in Palermo, just because the survey took place before the topic could be addressed during the dedicated course, which means that they are part of the university curriculum but could not be included in the present study.

It is worth stressing that open answers included both erroneous and misunderstood examples of 'daylight metrics'. For this reason, two groups were labelled 'other' in the Figure: (i) 'other-consistent' (21.9%), which includes a number of photometric quantities, such as luminous intensity and candela, Color Rendering Index and Correlated Color Temperature, luminance; (ii) 'other-inconsistent' (15.8%), which includes responses not related with a daylight metric, such as heat, comfort, wavelength, radiation, refraction, software, sun path, measurement instruments, transmittance, Waldram. This shows a certain level of confusion regarding the difference between variables, metrics, and units.

As for the application of daylighting metrics in projects within design studios or laboratories, 13.8% of the respondents reported to have had a direct application of at least one metric. This shows that the implementation of daylighting strategies into architecture practice (projects) is lower than the knowledge of the existence of metrics at a theoretical level, learned in theoretical courses. As shown in Fig. 5, the metrics that were applied into practice are

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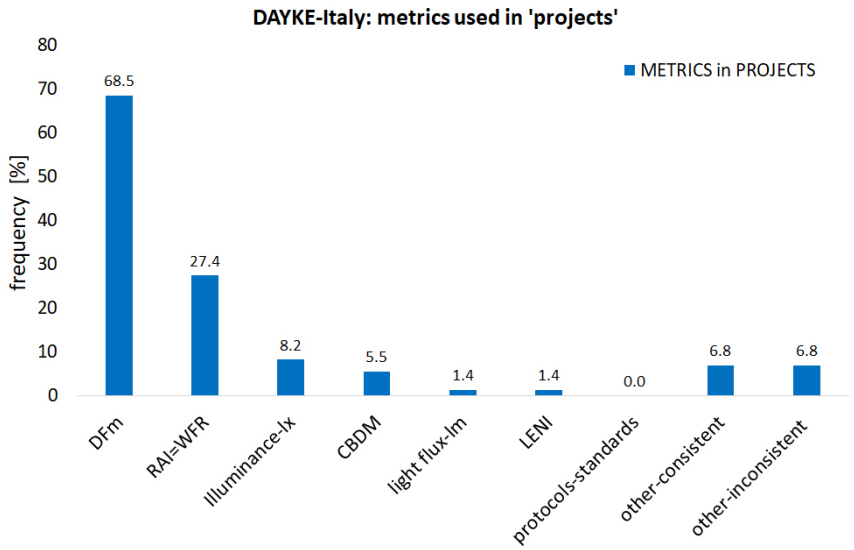

Fig. 5. List of metrics that were mentioned by students who reported to have participated in projects (design studios and laboratories) where daylighting was addressed. NOTE: the labels' *other-consistent*' and '*other-inconsistent*' have the same meaning as described in Figure 6.

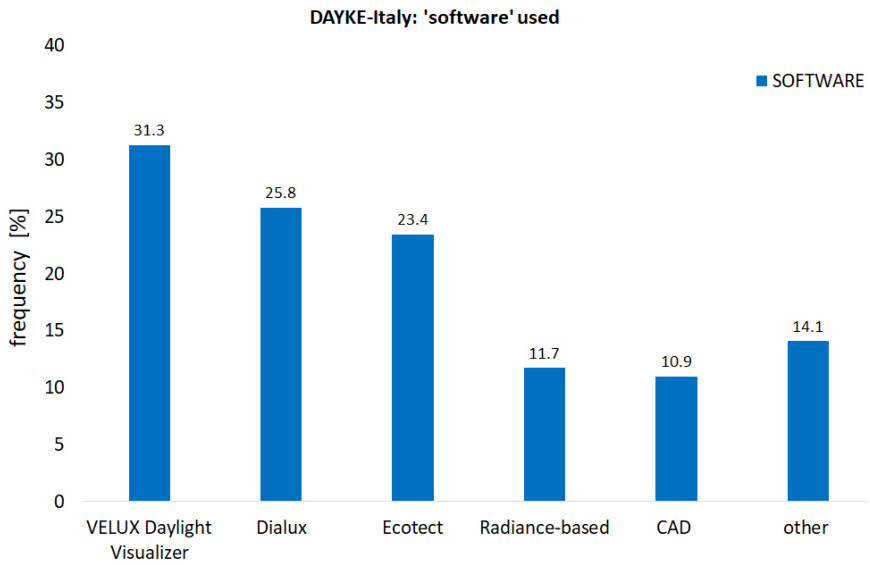

Fig. 6. Percentage of respondents who declared to know/have used daylighting software/calculation tools. NOTE: the label 'other' includes heterogeneous, non-daylight specific tools such as Keyshot, Photoshop, SunEarthTool, Termolog.

consistent with the metrics known at a theoretical level: DF_m (68.5%), WFR (27.4%), illuminance (8.2%), and CBMD metrics (5.5%). A differentiated analysis for the five cities considered shows an unbalanced distribution of the application of daylight metrics: most applications were reported in Turin, for instance, the percentage of application of DF_m was reported as high as 40%, while it was less than 4.5% for all the other sites considered. Similarly to what observed for the knowledge of metrics, a significant share of 'other-consistent' and 'other-inconsistent' responses was observed (6.8% for both cases).

4.1.2. Knowledge and use of simulation tools

Among the respondents, 25.1% of them reported to know or to have used a simulation tool for daylighting analyses. Figure 6 shows in detail which simulation tools were reported by the respondents for daylighting modelling.

The most cited simulation tools were Velux Daylight Visualizer (31.3% of students), Dialux (25.8%), and Ecotect (23.4%). Dynamic simulation tools that use Radiance (such as Daysim, DIVA-for-Rhino, Grasshopper and some of its add-on - Honeybee, Ladybug etc.) to perform dynamic daylighting modelling and calculate CBDM metrics were used by 11.7% of the respondents. A similar rate of answers (10.9%) was also attributed to a group of tools that included ArchiCAD, Cinema 4D, AutoCAD, 3D-Studio etc. A significant share of respondents (14.1%) mentioned tools that are not specific nor related to daylighting analysis, such as Keyshot, Photoshop, SunEarthTool, and Termolog. This latter is a professional software used to determine the energy certification of a building: it was probably cited with regard to the calculation of the energy demand for lighting as a result of the integration between daylighting and electric lighting.

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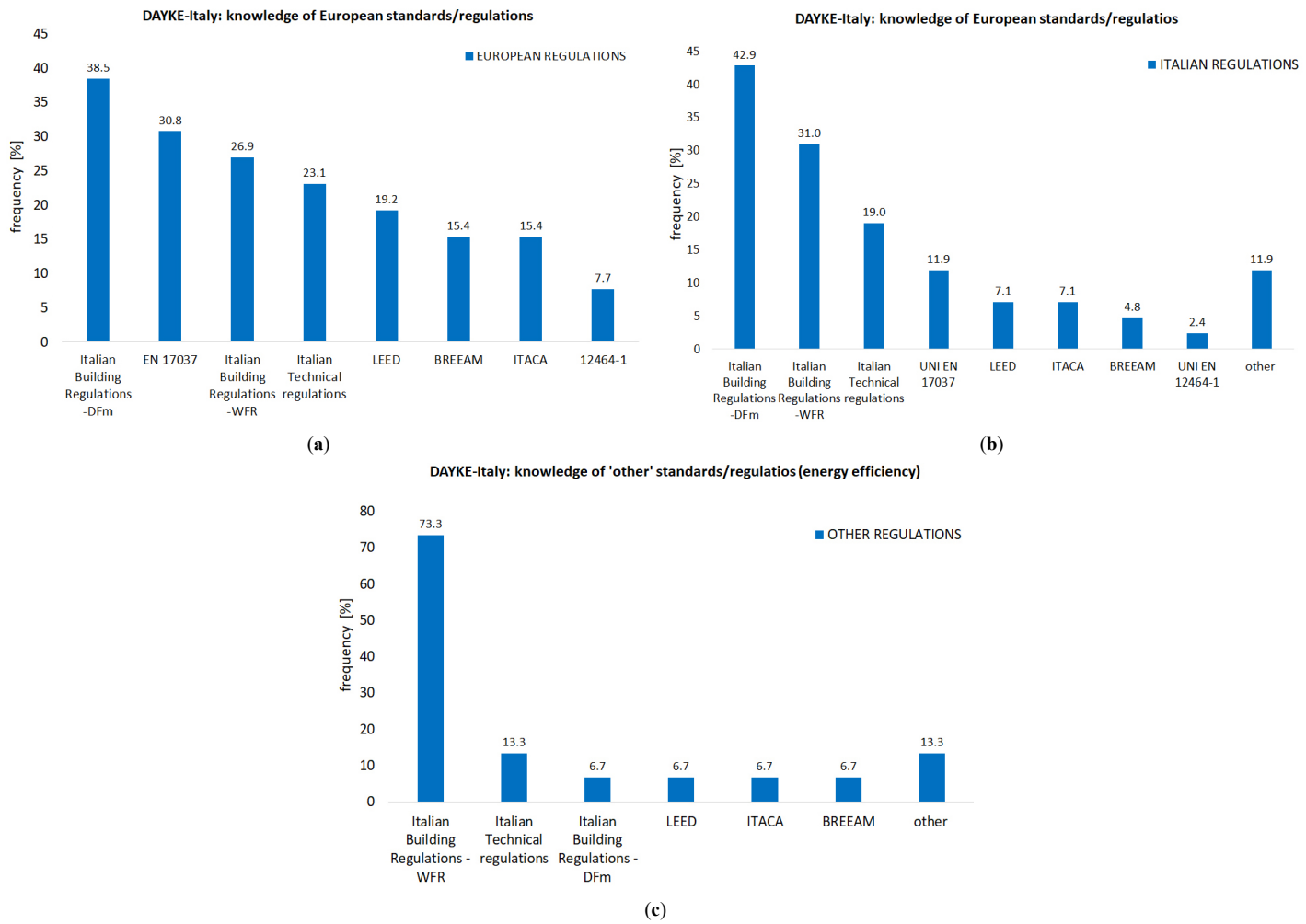

Fig. 7. Percent of respondents who declared to know at least one standard/regulation/protocol on daylighting: (**a**) European; (**b**) Italian; and (**c**) others.

4.1.3. Knowledge on daylighting standards, protocols and regulations

This section investigated the knowledge on European and Italian standards, regulations, and protocols on daylighting, as self-reported by the students.

A minor share of respondents reported to know at least one standard/regulation/protocol on daylighting: 5.2% about European standards and 8.1% for Italian standards. The rate of students who declared to know standards on energy-related aspects (labelled as 'other') was observed to be even lower (3.1%). As for the different universities, the peak of positive answers was observed in Turin and in Venice, with quite low rates for the other three sites (see Fig. 7).

Beside the low rate of responses, a general confusion also emerges in correctly mentioning the name of some standards, for instance mentioned in rough terms such as "standard that contains DF_m". Some confusion was also observed among European, Italian and other standards. For instance, the set of Italian regulations and standards on the average daylight factor DF_m was mentioned with regard to both Italian and European regulations, or energy/environmental protocols such as LEED [17] or BREEAM [31] were mentioned both among 'European' regulations and among 'other' regulations.

As for standards/regulations/protocols that were mentioned among *Italian* standards and regulations, the regulation codes that contain the DF_m prescriptions (technical regulations and Italian law decrees on residential, educational and healthcare buildings [31-35]) received the highest citation rate (42.9%), followed by the Italian regulations containing the WFR prescription (31%). This is consistent with the results observed about the knowledge of metrics, where DF_m and WFR were the most cited metrics. Among *European* standards and regulations, the recent European Norm EN 17037:2018 and environmental-energy protocols such as LEED [17] and BREEAM [31] were the most cited references (30.8%, 19.2%, and 15.4% of respondents, respectively).

4.2 RQ2: does the knowledge vary between bachelor and master students within DAYKE-Italy?

Figure 8 shows the frequency of positive answers that were expressed within DAYKE-Italy, deduced the FP inconsistent answers, disaggregated for B.Sc. and M.Sc. students. The number of FP responses is also shown in the Figure.

As one could expect, the rate of positive answers increases among M.Sc. students compared to B.Sc. students for all the aspects of daylighting knowledge investigated. In detail, the following trends can be highlighted:

- Metrics: the rate of positive answers is more than doubled comparing M.Sc. to B.Sc. students, increasing from slightly less than on fourth of B.Sc. students (24.1%) to almost half of

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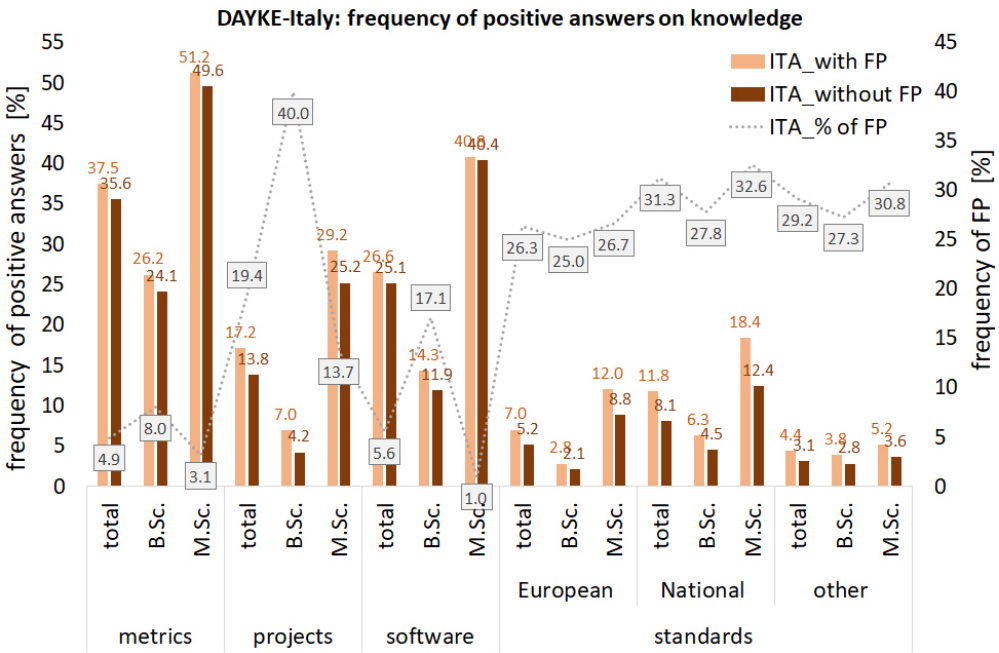

Fig. 8. Frequency of positive answers to the various aspects of daylighting knowledge investigated, differentiated for B.Sc. and M.Sc. students.

the sample of M.Sc. students (49.6%). The χ^2 test confirms the increase as significant: $\chi^2(2)=38.873$, $p<.001$. Therefore, it emerges that there is a general awareness about daylight metrics among M.Sc. students.

- Projects where daylight metrics were used: the rate of positive answers shows a significant increase comparing M.Sc. to B.Sc. students (25.2% vs. 4.2%, $\chi^2(3)=52.450$, $p<.001$). This seems to show that the daylighting issues remain barely addressed in design studios and laboratories in the B.Sc. curriculum, while they play a more important role in design studios/laboratories in the M.Sc. curriculum. This rate is increased among M.Sc. students, but it appears to be still low, as only a fourth of them reported to have used daylighting in a project. Even though not statistically significant, a high rate of FP was also observed for the participation in projects where daylight metrics were used among the B.Sc. students (40%) compared to M.Sc. students.
- Software: the rate of positive answers shows a significant increase comparing M.Sc. to B.Sc. students (40.4% vs. 11.9%, $\chi^2(2)=60.219$, $p<.001$). This seems to indicate a general familiarity with software for daylighting modelling, but it should be noted that such familiarity does not reach 50%.
- Standards: a general increase in the rate of positive answers was observed comparing M.Sc. to B.Sc. students, but it still remains low, as the highest rate was 12.4%, reported for knowledge of national standards/regulations. A general lack of knowledge about legislations and regulations emerged. The chi-square tests showed that the differences were significant for European ($\chi^2(2)=17.271$, $p<.001$) and national standards ($\chi^2(2)=18.580$, $p<.001$). However, the analysis showed that regarding European and national standards, M.Sc. students also reported a significantly higher number of FP responses compared to B.Sc. students.

Considering the average rates reported by B.Sc. and M.Sc. students on all the six items of knowledge (metrics, projects, software, and three types of standards/regulations), the average knowledge increased from 8.3% to 23.3%: this shows that M.Sc. curricula implement a higher awareness on daylighting aspects, even though such knowledge still appears quite low. This is mainly due to the scarce knowledge on standards/regulations: the average rates reported on metrics, projects, and software are higher, being 38.4% among M.Sc. students compared to 13.4% among B.Sc. students. Still, less than half M.Sc. students are familiar with daylight metrics and software, with a quite low implementation and application of daylight issues in projects.

4.3 RQ3: Are results collected through DAYKE-Italy comparable to results collected through DAYKE-Europe?

In this section, the answers collected about daylighting knowledge within DAYKE-Europe and DAYKE-Italy are compared, with the aim of highlighting if the trend in Italian universities is somewhat in line, or better, or worse with respect to the average knowledge observed in Europe [22].

Figure 9 shows the frequencies of positive answers provided by the respondents on the various items on 'knowledge about daylighting', with regard to both the total of students and disaggregating B.Sc from M.Sc students. FP responses were not displayed in the graph.

The following trends emerge, with regard to the various aspects of daylighting knowledge addressed through the survey:

- Metrics (knowledge of daylight metrics/indicators): a slightly higher frequency of 'yes' was observed in the Italian sample (35.6%) compared to the European sample (31.6%): the discrepancy is significantly higher among M.Sc. students (49.6% vs. 37.1%, ($\chi^2(2)=7.731$, $p<.05$), while the opposite trend was observed among B.Sc. students (29.9% vs. 24.1% in favor of European students, not statistically significant).
- Projects (participation in projects where daylight metrics were used): a similar trend was observed compared to that found for 'metrics', with a slightly higher frequency of 'yes' in the

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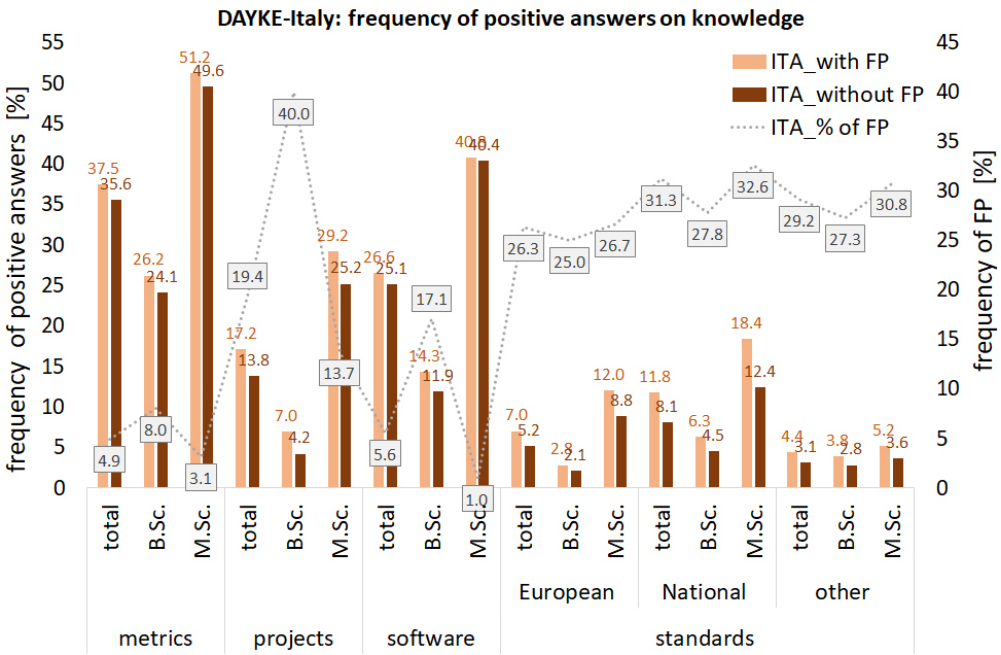

Fig. 9. Percent of respondents who declared to have knowledge of daylighting metrics, regulations, and software in DAYKE-Italy and in DAYKE-Europe.

Italian sample (13.8%) compared to the European sample (12.3%). The difference is due to the responses given by M.Sc. students (25.2% vs. 15.5%), while the opposite trend applies for B.Sc. students (11.4% vs. 4.2% in favor of European students), with a statistically significant difference found for both M.Sc. and B.Sc. students: $\chi^2(2)=7.731$, $p<.05$. These findings show that: (i) knowledge of daylight metrics appears to be mainly theoretical within both DAYKE-Europe and DAYKE-Italy, i.e. learnt in theoretical courses, as the frequency of students who participated in projects where such metrics where applied is far lower than that observed among students who declared to know at least one daylight metric; (ii) the M.Sc. curricula in the Italian universities involved in DAYKE-Italy seem to offer more design studios and laboratories where to apply daylight metrics compared to the M.Sc. curricula in the European universities involved in DAYKE-Europe, while higher opportunities seem to be offered in European B.Sc. curricula compared to Italian ones.

- Software (use of daylighting software): once again, the trend is consistent with what was observed for topics 'metrics' and 'projects'. The frequency of 'yes' was higher within the Italian sample (25.1% vs. 20.7%, $\chi^2(2)=7.047$, $p<.05$)), with an opposite trend relative to B.Sc. and M.Sc. students: among M.Sc. students, the frequency of 'yes' was quite higher for Italian students (40.4% vs. 20.7%, with no statistically significant difference), whilst among B.Sc. significantly more European students declared to know at least one daylighting software compared to their Italian colleagues (21.5% vs. 11.9% in favor of European B.Sc. students, $\chi^2(2)=7.047$, $p<.05$). The higher percentage of students who have used simulation tools for daylighting analyses among Italian M.Sc. students seem to be consistent with the higher number of projects in which Italian students participated and calculated daylight indicators through simulation tools.
- Standards/regulations (standards, legislations and regulations on daylighting): the frequency of 'yes' is higher among Italian students compared to European students with respect to knowledge of European standards (even though the difference is not statistically significant), while the opposite trend applies with regard to national (13.8% vs 8.1%, $\chi^2(3)=44.921$, $p<.001$) and 'other' (energy efficiency, solar gains) standards (11.0% vs 3.1%) ($\chi^2(3)=98.589$, $p<.001$) investigated. Analyzing the performance of B.Sc. and M.Sc. students, the chi-square tests showed that European B.Sc. students reported significantly higher knowledge on national and other standards, compared to their Italian counterparts ($\chi^2(3)=47.129$, $p<.001$) and $\chi^2(3)=59.491$, $p<.001$, respectively for national and other standards. Similar differences were found for M. Sc. students regarding knowledge of other regulations, with European students performing significantly better than the Italian ones ($\chi^2(3)=39.480$, $p<.001$).

When the overall knowledge performance (total score by summing the positive answers of items 1 through 6, deduced FP responses) was considered, the ANOVA showed a significant main effect of Degree curriculum ($F(1,829)=8.730$, $p=.003$) and Nationality ($F(1,829)=83.556$, $p=.000$), as well as a significant interaction effect of Degree curriculum * Nationality ($F(1,8299)=21.136$, $p=.000$). In more detail, this means that:

- M.Sc. students reported a statistically significantly higher level of knowledge compared to B.Sc. students (total score: 2.083 vs. 1.666).
- European students reported a significantly higher knowledge compared to Italian students (total score: 2.519 vs. 1.230).
- European B.Sc. students reported a significantly higher knowledge compared to their Italian counterparts (total score: 2.635 vs. 0.698).

Following up the approach reported in Section 4.1, which showed a quite high impact on the results played by FP responses (especially concerning 'projects' and 'standards'), Figure 10 compares the FP responses that were identified for both samples,

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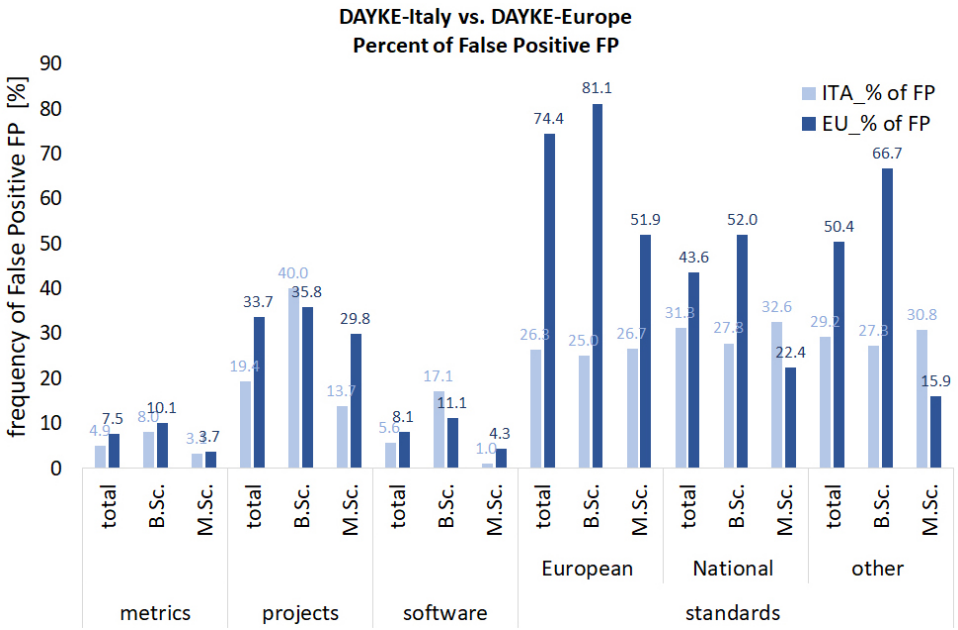

Fig. 10. Percentage of 'false-positive' responses expressed on knowledge of daylighting metrics, regulations, and software in DAYKE-Italy and in DAYKE-Europe.

DAYKE-Italy and DAYKE-Europe. Based on the results shown in the Figure, the following considerations can be drawn:

- The number of FP appears considerably high, especially for some of the knowledge aspects investigated, with a peak percentage of FP = 40% within DAYKE-Italy and even higher (over 80%) within DAYKE-Europe.
- As far as the knowledge of daylight metrics is concerned, FP are quite low (with a peak value of 10.1%) for both the Italian and the European samples. It seems therefore that both Italian and European students clearly identified how to address this item.
- A similar trend was observed for the item 'software', with a peak of FP of 17.1%.
- Differently, the frequency of FP increases for the item 'projects' (peak of 40%) and to a higher extent for the item 'standards' (peak of 81.1%). It appeared that especially European students had difficulties in specifying in which project they applied daylight metrics (after answering 'yes' to the dedicated question) ($\chi^2(3)=19.922$, $p<.001$) or in mentioning a standard (again, after answering 'yes' to the dedicated question) ($\chi^2(3)=49.230$, $p<.001$; $\chi^2(3)=44.921$, $p<.001$; $\chi^2(3)=98.589$, $p<.001$ respectively for European, national and other standards). This may be due to some problems in remembering the precise name or identification number.
- A significantly higher rate of FP responses was recorded among European B.Sc. students compared to their Italian counterparts regarding the item 'projects' ($\chi^2(3)=25.923$, $p<.001$) and the knowledge of European ($\chi^2(3)=43.317$, $p<.001$), national ($\chi^2(3)=43.317$, $p<.001$) and other ($\chi^2(3)=59.491$, $p<.001$) standards.

5. Discussion

5.1. Discussion on results

Some of the most interesting findings are discussed below:

- Concerning the knowledge of metrics, the most cited daylight metrics were the average daylight factor DF_m and the window-to-floor ratio WFR. It is worth mentioning that DF_m is the reference daylight metric to quantify the daylight provision (and to determine the minimum glazed area in a room) according to Italian legislation [32-36]. In this sense, almost two-thirds of the respondents (60.2%) showed to have knowledge of the most relevant daylight metric from a legislation viewpoint. On the other hand, the WFR (mentioned by 36.1% of students) is a requirement for ventilation purposes [32], as it represents the ratio of the window area that can be opened to the floor area. It is included in some Italian building regulations (WFR> ⅛) and it is widely used among building practitioners and professionals as a daylighting criterion. Moreover, it is commonly taught in several architecture courses starting from the Bachelor of Science curriculum. As a result, it is not surprising that a ventilation metric was mentioned as a daylight metric, beside DF_m (and often in replacement of it). Other metrics that were mentioned as daylight indicators were illuminance (sometimes referred to by its unit 'lx' rather than by 'illuminance') or luminous flux. This shows that some respondents did not understand correctly the concept of 'daylight metric/indicator' itself. Furthermore, it is also worth noticing that the knowledge of climate-based daylight metrics (DA, sDA, UDI, DGP) is still quite low, as it was reported by slightly more than one participant out of 10 (11.5%). This is also confirmed by the even lower rate of students who applied CBDM metrics into their projects (5.5%), even though 52.4% of students reported having previously attended at least one course during their curriculum that addressed daylighting analysis and/or calculations. Such findings show that there still is a quite massive gap between the evolved, yet more complex, CBDM approach and its implementation into architecture curricula, but unfortunately this is consistent with the fact that CBDM metrics are not included in any Italian

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legislation. The EN 17037:2018 standard, adopted by the Italian Standardization Body (UNI) in 2019, has not been implemented into any formal legislative document, while CBDM metrics have not been introduced in any legislation yet (apart from the DGP in the above-mentioned EN 17037:2018). As a consequence, the Italian regulation system still refers to the traditional (and obsolete) average DF_m concept.

- Several false-positive FP data was observed, both for students who were unable to specify what they knew after stating that they knew a specific subject matter ('missing responses') and for students who reported inconsistent metrics, software, or standards ('inconsistent responses'). Missing responses were found to be particularly high about 'standards' and 'participation in projects where daylight metrics were used' (by B.Sc. students). In general, there seems to be some confusion among the respondents, especially about standards (European, Italian, 'other' standards such as standards on energy). Confusion over terminology has also been found for metrics, software and energy protocols. A possible explanation for this can be the difficulty in remembering, at the time when the DAYKE questionnaire was filled, a standard learnt in earlier semesters or years. This can lead to skip the question or to make confusion and mistakes when mentioning a European rather than a national standard. Another explanation may be that standards are not extensively analysed and applied to projects through design studios and laboratories, thus remaining more 'theoretical' and insufficiently used in practice.
- A significant increase in the knowledge level about daylighting issues was observed among M.Sc. students, compared to B.Sc. students. Daylighting knowledge among B.Sc. students are remarkably low, which is something to think over as B.Sc. students can work as professionals after they gained their B.Sc. degree in Architecture. In such a case, they would not have enough education on daylighting to promote the development of sustainable architectures.
- The findings from DAYKE-Italy are in line with what observed within the earlier DAYKE-Europe [22]: in both surveys, the knowledge about daylight standards and regulations is meager, opposed to a higher knowledge of daylight metrics and simulation tools. Compared to European students (DAYKE-Europe), Italian students showed a higher knowledge of daylight metrics and software (especially M.Sc. students), while the opposite was observed for standards, regulations, and protocols.

In general, the level of knowledge remains low, especially among B.Sc. students. This suggests that a lack of knowledge of standards and requirements may lead to the limited implementation of daylight in the design process or design decisions that do not fully exploit daylight potential. The skills learned in courses seem to remain at a theoretical level and have limited application to projects. The results of the first DAYKE publications show that the culture of daylight is not widespread enough in schools of architecture. Furthermore, this is in contrast with the orientation towards sustainability that is increasingly being given more and more space in training of architects. Hence, there seems to be an urgent need for a revision of university curricula to dedicate more importance to daylighting education, with greater consistency with teaching energy aspects. Even where changes in university curricula may be slower, individual teachers (especially in the fields of building technology and physics) could introduce dedicated lessons to increase knowledge of aspects, metrics and regulations relating to daylighting.

Finally, the authors would like to draw attention to a trend that was observed in the open-ended responses and that goes beyond a purely theoretical aspect, i.e. the confusion over the terminology of false-positive - inconsistent responses. Some diffuse confusion over technical terminology was observed for a minor share of the respondents. Recurrent confusions were: units of measurement mentioned for metrics and indicators; energy protocols mentioned for standards and norms; building components mentioned for metrics and indicators; software mentioned as standards or metrics. The possibility of introducing bias into the questions was considered and, to reduce the misunderstanding factor, the questionnaire was translated into the languages of countries where English is less familiar (Italian, French, Polish). In spite of this, the number of FP remained significant in some cases. This confusion and misunderstanding may be a good reference to include in the process of revising university curricula.

5.2 Innovation and limits

The DAYKE project is an extensive survey, still in progress, trying to have an exhaustive vision on an educational issue - daylighting - at an international level. One of the strengths of the project is the development of ad-hoc questionnaires, specifically designed to incorporate the views of both academic and non-academic populations (professionals). Focusing on the main topic dealt with in the present paper, '*knowledge on daylighting*', the DAYKE-Italy project, like the earlier DAYKE-Europe, has the merit of investigating and reporting on the gap that still exists between daylighting research and daylighting education in architecture curricula. On the one hand, research has validated the climate-based daylight modelling CBDM and the set of CBDM metrics that have been proposed over the last 15 years, some of them being incorporated in energy-environmental assessment protocols such as the LEED v4.1 (2020) [17]; in this frame, the recent European standard EN 17037:2018 introduced a 'climate-based' version of the average daylight factor DF_m and adopted the Daylight Glare Probability. On the other hand, the Italian legislation system still refers to DF_m, which means that the CBDM approach and its metrics are not standardized as reference and hence remain largely under-used.

On the whole, DAYKE-Italy has the merit to highlight a general low level of knowledge on daylighting among architecture students. This particularly applies to B.Sc. students. Results from DAYKE-Italy highlight the need for a deeper implementation of daylighting to educate the next generation of building professionals and practitioners in a sustainable perspective. Today's students will be professionals in a span of a few years. At that time they will have to design by applying CBDM or circadian metrics and new standards in the field are expected to be more and more extensively implemented into building legislation and regulation systems. A great effort is needed to bridge the gap between advances in daylighting research, which nowadays also includes effect on the health of occupants of indoors spaces, through the 'non-visual' effects of light and their impact on the individual circadian rhythm, and a conscious application to the

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design process. This is a core issue in the frame of achieving a 'human-centered design, as daylight combines health, psychological effects for the global well-being of the occupants of indoor spaces. Otherwise, there is a risk that 'human-centered design' remains an appealing but theoretical label.

Among the limits, it may be highlighted that the sample of five universities that was used within DAYKE-Italy cannot be considered as fully representative of all the Italian architecture curricula. In order to obtain more generalizable results, a wider range of universities may be included as a further development of the research. This might be coupled with a more in-depth analysis of the curricula offered by the different universities and schools of architecture. On the other hand, the sample used within DAYKE-Italy was large enough to identify a number of shared and significant trends about implementing daylighting design into the education process of Italian architecture students.

Using the results obtained from the DAYKE research, an international project funded by the Erasmus+ programme was set up to create a platform to increase daylight education for both students and building professionals [37]. The project, which is still in its early phase, is expected to bring the discussion on daylight issues to a higher level of awareness.

6. Conclusions

The paper presented some results from the DAYKE-Italy project, which administered an ad-hoc online questionnaire to both B.Sc. and M.Sc. architecture students to investigate various aspects of knowledge about daylighting (daylight metrics and simulation tools, participation in projects where daylight metrics were used, and standards/regulations). DAYKE-Italy is a methodological replication of the DAYKE-Europe project to the Italian context, and it was set up also to explore if such knowledge is aligned with the average knowledge observed within DAYKE-Europe. A total of 542 questionnaires were collected from five universities.

The main findings were: (i) a general low level of knowledge was observed on both daylighting metrics, software and standards; the most cited metrics were the DF_m and the geometrical window-to-floor ratio WFR (window area to floor area ratio); (ii) the advanced climate-based daylight metrics were mentioned less frequently than DF_m and WFR; (iii) M.Sc. students reported more knowledge than B.Sc. students on all the aspects of daylighting knowledge; particularly, the implementation of daylighting metrics and strategies in architectural projects was very low among B. Sc. students; (iv) compared to European students (DAYKE-Europe), Italian students showed a higher knowledge of daylight metrics and software (especially as for M.Sc. students), while the opposite was observed for standards, regulations and protocols.

In conclusion, the study pointed out a quite low implementation of the latest research findings into both the regulation systems (even though the recent European Standard EN 17037:2018 [13] represents a meaningful step forward in this direction) and in the educational programs. It was also possible to understand that both teaching and implementation of daylighting into the architecture curricula is limited, which strongly reduces the possibility of educating a class of future building designers and practitioners who can enhance the crucial benefits of daylighting (in terms of comfort, health, and energy savings) in their professional career. More robust implementation of courses on daylighting design is therefore recommended in university curricula in Italy. Considering the multi-faceted aspects of daylighting (cognitive, physiological, and psychological), it is important to address daylighting education through a holistic, multi-disciplinary approach that combines expertise from technical and human sciences.

This paper aims to open a deep thinking on what is taught in Italian and European universities currently. Today's students will be professionals within a few years and will carry on the marks of their education. Some urgent questions need to be addressed: will future building practitioners really be able to design through CBDM or circadian lighting design? The issue is also broader and involves how the new regulations and standards are presented to students. Will universities be able to train the professionals of tomorrow, consistently with the new goals set by the United Nations for a sustainable and inclusive development?

Contributions

Federica Giuliani conceived the idea of the study, elaborated the results from questionnaires and prepared the data for analysis.
Valerio R.M. Lo Verso supervised, distributed and managed the survey distribution and data collection and analysis, together with Federica Giuliani and Federica Basile. Furthermore, he wrote the text of the paper.
Federica Basile managed the distribution of the survey and prepared data elaborations.
Federica Giuliani, Valerio R.M. Lo Verso and Federica Caffaro designed the questionnaire and equally participated in the data analysis phase.
Federica Caffaro and Federica Giuliani revised the text of the paper.
Fabio Peron, Tiziano Dalla Mora, Laura Bellia, Francesca Fragliasso, Marco Beccali, Marina Bonomolo, Francesco Nocera, and Vincenzo Costanzo participated in the survey distribution and data collection and analysis.

Declaration of competing interest

The authors declare that there is no conflict of interest.

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