Practices in Timetabling in Higher Education Institutions

A systematic review

Rudy A. Oude Vrielink · Daniël Schepers · Erik A. Jansen

Abstract The study of differences between timetabling research presented in conferences like PATAT, and the timetabling software used in Higher Education Institutions (HEIs) is essential for the discussion about innovation in HEIs. In the field of planning and scheduling, a lot of developments are made and it is important to recognise that these developments are of some influence on HEIs. A main objective of the work presented here is to provide up-to-date information about timetabling in higher education institutions and see to what extent they adopt and implement timetabling developments. This seems crucial because of budgets of institutions being cut and remaining resources like rooms having to be shared more and more. This has caused planning processes in higher education to deal with more limitations than ever, while at the same time the demand towards flexibility and availability is increasing. This paper gives the results of a systematic literature review in which differences and similarities in theory and practice of timetabling in higher education are described and discussed. We looked at state-of-the-art timetabling in HEIs and its innovation in the field of timetabling and the use of space. The aim of this paper is to motivate the discussion about both the differences and similarities and bring timetabling research closer to educational requirements.

Keywords higher education · education logistics · timetabling · trends · algorithms

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1 Introduction

Nowadays, a paradigm shift is occurring in the field of education logistics. Instead of a continuous growth because of increasing numbers of students, higher education institutions, referred to as universities and colleges of higher education, have to deal with an onset shift of centralising and diminishing resources like classrooms and housing due to budget cuts. In most national systems, those budgets are tied to national expenditures, which are based on public policy [1].

The traditional and more conventional view on education is gradually transforming into a student-central hands-on learning platform where practices of rote learning are being less applied [2]. Moreover, people are more likely now than before to study at other HEIs or participate in courses offered for distance education. Tools like e-learning and MOOCs emerge from educational technology and help to opt for those choices. Therefore, most HEIs tend to offer learning programs and courses which enable students to develop a new set of skills they can use to adapt to the demands of the changing world. Instead of following a fixed curriculum scheme, a modular approach is more often chosen in which various specialisation options are being offered.

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1.1 Closer look

The combination of the receding availability of shared resources and increasing demands, causes HEIs to adapt their timetabling practices in order to maintain quality of studiability, suitable timetables for support staff and the degree of efficiency, whilst maintaining the educational quality levels. Studies have shown these problems in the field of timetabling to cause dissatisfaction amongst students, staff and organisation. It is not just the possibilities that increase but also the expectations are much higher.

When searching scientific literature databases one can notice that writings about timetabling practices in higher education are being published in increasing numbers in the last decade (2005-2015). Those writings include publications in the field of timetabling in higher education, practices and tools, timetabling algorithms, etc. Figure 1 reflects this trend when, for example, Google Scholar is accessed with searching terms "(Timetabling OR Timetable) AND Higher education".

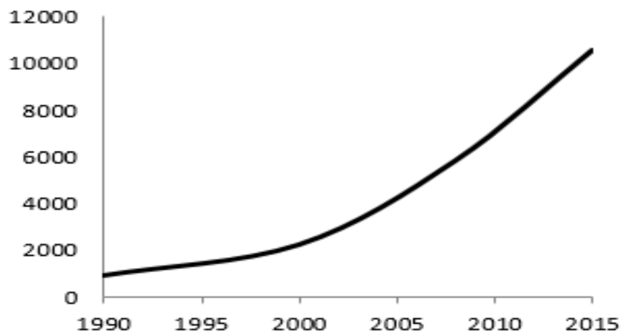

Fig. 1 Number of papers on timetabling in HEIs.

The increasing amount of literature suggests that more research is being conducted in the broader field of education logistics. This paper designs a classification in which state-of-the-art timetabling in higher education is listed. The goal is to look at notable differences in approaches described in recent literature and real-life implementations.

Conducted research in timetabling in HEIs has advanced rapidly in which practices and theories have been developed and elaborated increasingly [4]. However, a lot of papers discuss situational topics based on environmental characteristics [5], making it essential to identify and differentiate between those characteristics and developments for giving a state-of-the-art overview of timetabling in HEIs. Conducting this research enables us to investigate gaps between theory and practices of methods and processes used in this research domain. This review also helps us to orient on this field of research in order to provide insights for future research.

2 Method of research

The increase in the output of research publications in the field of timetabling in HEIs has led to the fact that it is more difficult to keep track of what work has been established of the various aspects within this field. In order to find out what is state- of-the-art in both the research and in practice, we researched timetabling by identifying evidence, trends and conclusions in relevant studies. Within framing this research, the relations between the components of the problem have to be established and displayed. Figure 2 shows those relations:

The research plan consists of two main subjects: Developments in timetabling and characteristics of HEIs. This paper aims to give rise to research and discussion about practical applications and actual software used, but does not

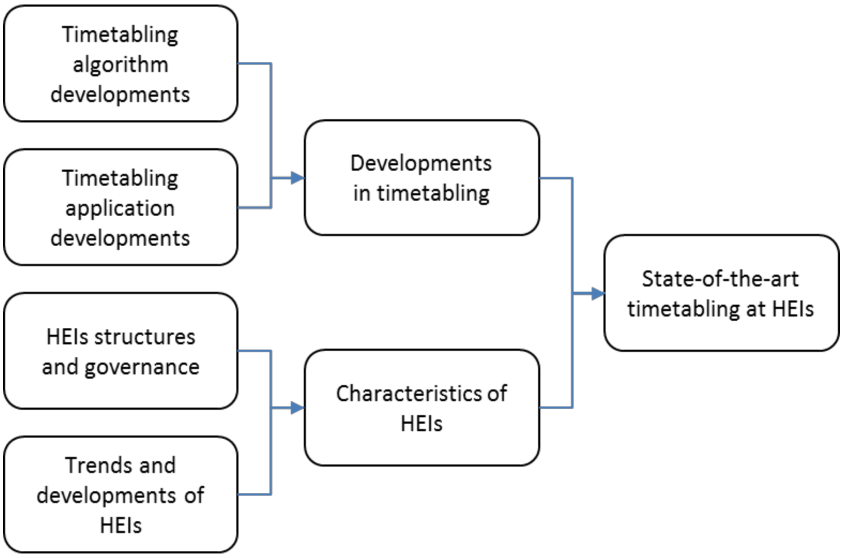

Fig. 2 Research plan.

discuss actual software used in higher education, which is undoubtedly interesting in order to further support this paper but it is not in the scope.

An up-to-date overview of timetabling in HEIs consists of listing developments in timetabling in combination with the operational and structural characteristics and developments of HEIs. Developments in timetabling encompass research in timetabling domains, with trends and developments of timetabling algorithm developments and timetabling software application developments. Characteristics of HEIs emerge by describing HEIs governance and structures, together with trends and developments of HEIs. The combination of both the characteristics of HEIs and developments in timetabling is a synthesis as a view on state-of-the-art timetabling within HEIs and in which gaps between theory and practice can be identified.

3 Developments in Timetabling

This chapter describes developments in solving timetabling optimisation problems. First, the timetabling problem is explained in further details to give a clear understanding of a lacking general solution for timetabling. The second part outlines the advancements of automated timetabling throughout the years. Finally, a comprehensive view of several ways to solve timetable problems is outlined.

3.1 The timetabling problem

The constantly moving research field of timetabling has caused rapid developments in theory and practice. Wren (1996) [27] defined timetabling as: "The allocation of given resources to specific objects being placed in space time, in such way as to satisfy as nearly as possible a set of desirable objectives, subjected to constraints." The presence of knowledge for creating timetabling software has led to new insights, like improved methodologies and more comprehensive models [5]. Besides this, an increased effectiveness of the timetabling process is notable. Appropriate resources are to a greater extent linked to needs of users as well as staff and student. Moreover, those developments encouraged new approaches for space utilisation strategies and interactive timetabling [35, 45]. Timetabling applications are nowadays capable of applying new techniques and solution algorithms. Techniques and algorithms are taking more and various factors into account like performance issues, constraint requirements and student/personnel interests.

However, the variety of constraints, the diversity of the problem and specific requirements have caused finding an effective and general solution in timetabling to become more difficult [11]. There are different kinds of scheduling problems now and timetabling is stated to be a common problem in this area. The timetabling problem is a so-called NP-hard and NP-complete optimisation problem, depending on the constraints [9]. Feasible, efficient or fast solutions are all synonyms for polynomial time. Yet, none of these apply to the field of timetabling, which means that most of the timetabling challenges are not solvable within a realistic time frame. For these kinds of problems, computational heuristics are often taken into account as a solving strategy, resulting in a non-optimal but hopefully feasible solution [10]. Despite the amount of literature and research dedicated to this problem, a gap still exists between reality and models used, or, in other words, between theory and practice. This is discussed by McCollum (2006) [5], who identified that it is extremely difficult to find a generally applicable model whereas different institutions recognise different constraints. Many studies that attempt to propose a model use specific datasets for proving their solution or model [27–29], which to a certain extent excludes generalisability. However, in order to propose an institution-wide timetable a comprehensive formulation of the problem has to be made in which the problem is relevant to real world practices. McCollum emphasises that solutions for this problem must address a wider range of these practices rather than fine-tuning algorithms or meta-heuristics on particular datasets used.

3.2 Research in timetabling domains

Timetabling covers a variety of areas in which a significant amount of research has been conducted. Those broad domains encompass planning and scheduling of educational-, transport-, employee-, sports- and healthcare settings.

Within educational timetabling, school timetabling and university timetabling for courses and examination are most studied. However, research in the area of school timetabling has not advanced as rapidly as university examination and course timetabling [22]. This is due to the fact that studies are done in specific schools, in isolation [23], in contrast to university examination and course timetabling where more methods are compared for a set of problems or constraints instead of a study for a single institution.

A significant amount of surveys on educational timetables has been conducted in the past 10 years. This includes literature presented at conferences that are dedicated to timetabling practices, like Practice and Theory of Automated Timetabling (PATAT) and Multidisciplinary International Scheduling Conference: Theory & Application (MISTA), both alternatingly held every two years. One of the areas of their research covers methodologies for specific domains of timetabling. Those methodologies aim to solve, but rather optimise, timetabling problems. The construction of the solutions depends on how the timetabling problem is defined. The problem describes constraints variances and requirements and thus may alter from institution to institution. In recent studies, researchers use standardised formulations of those problems. Bellio (2014) [26] describes the most used variants in the education domain of timetabling. The problem is translated into a specific benchmark set and methodologies. Solutions and models are evaluated on those sets. Hence, researchers aim to evaluate their solution on multiple datasets in order to test for generalisation rather than specification, which is in line with what McCollum advocates. Recent timetabling competitions foster the emergence of standardized benchmark data sets that also aim to provide a “real-world” application.

3.3 Trends and developments

A notable amount of developments regarding timetabling methods and algorithms can be found in studies, surveys and literature. This paragraph aims to outline those developments. Subjects covered in this paragraph elaborate on the developments described in the preceding paragraphs in order to classify them.

3.3.1 Timetabling algorithms developments

In this section, solutions to solve timetabling problems are discussed. These solutions are differentiated among various fields of heuristic optimisation algorithms [71]. Based on literature, a profound chronology of metaheuristics is provided and is briefly elaborated on. However, these fields are not mutually exclusive. A notable amount of metaheuristics algorithms combines ideas from these different fields, which are called hyper-heuristics. The aim is to provide different ways of finding solutions for the timetabling problem discussed. The chronology consists of a trichotomy, which is about grouping and declaring similar events occurred in various periods of time.

Up to 1995. Welsh and Powel represented graph colouring strategies for solving timetabling problems. They built the foundation for more sophisticated research on graph heuristics in timetabling [55]. Graph colouring timetabling heuristics are constructive methods in which the construct is evaluated on and being improved. Linear and integer programming techniques are mathematical based algorithms and assign integral values to variables. Variations of this technique were, and still are, a widely used method to solve combinatory optimisation problems. Constraint based techniques originate from research on artificial intelligence [56]. These techniques encompass constraint logic programming and constraint satisfaction techniques. However, such techniques are generally computer extensive by means of increasingly exponential amount of variables. In more recent literature, constraint based techniques are integrated with different heuristics and techniques in order to keep up with other state-of-the-art techniques.

1995–2010. In the late 90s of last century, methodological approaches for solving timetabling problems were in general being classified into two categories of meta-heuristics: population-based approach and a single-based approach [57]. Starting with many candidate solutions, a population-based approach aims to find the best solution in the search space. The solutions are refined in a parallel optimisation environment. A single-based approach works with a single solution and then tries to improve for a better result. The constraints are satisfied in an iterative manner.

Tabu search falls under local search methodologies and is based on steepest descent search as it tends to explore the search space by not re-interpreting recent moves. There are several relevant papers which carried out a valuable investigation of Tabu search techniques [58,59]: (1) Diversification of the neighbourhood whereby the search is extended to find more local optima and (2) Intensification of steps made in Tabu search algorithms to find faster solutions. Simulated annealing (SA) is another local search technique. This technique aims to search for a wider area of search space in which worse steps are accepted and allows for a more extensive search for the optimal solution. SA encompasses a certain amount of variants [57,60] but is often combined with hill climbing techniques [43] and constraint programming [56]. In line with local search based techniques, a recent trend recognises the definition of more different neighbourhoods. Structures like variable neighbourhood search [62] and large-scale neighbourhood [63] search are associated with such techniques.

In the subdivision of population based algorithms, evolutionary algorithms encompass a major set of population based techniques. Genetic algorithms are most common and studied among the evolutionary algorithms. Corne et al. (1994) [66], conducted a research on the use of genetic algorithms in educational timetabling and provided a survey on this. Such algorithms are based on best individual solution in the population space and each best solution provides the basis for a new evolutionary cycle [74]. A survey of Burke et al. (2009) [43] discusses different kinds of applications of genetic algorithms and how these algorithms are modelled. Memetic algorithms [65] is seen as an addition of genetic algorithms. Memetic algorithms are mostly supported by local search methods and have the ability to explore a region of population based method with local search techniques. It is, however, challenging to find a right balance between exploitation of local search and exploration by means of population based methods of the search space. Alkan et al., [75] elaborated in their study on the use of memetic algorithms in timetabling. They acknowledge the need to keep a diversified population in order to maintain a right balance of the search space, as mentioned before.

Another population based technique which is researched on in greater depths for the last decade is the group of ant algorithms [64]. These algorithms keep track of information gathered during a search, subsequently, this information is used for generating new solutions in next stages [43].

Recent. Both single- and population based approaches have their drawbacks. The main drawback of a single-based approach is that the main focus lies on exploitation rather than exploration. This means that the search space is limited to one trend or solution for the current situation. Other solutions, however, are not considered. On the other hand, population based algorithms often experience premature convergence because of the lack of concentration on current solutions in the search space. Local optima in this search space are made progressively similar to each other, causing a loss of diversity. Lately, most timetabling researchers have focused on local (single) based solutions rather than populated based algorithms [17]. A development that emanated from standard local and population based solution for timetabling problems is the application of hyper-heuristics. Hyper-heuristics, in contrast to meta-heuristics, search for solutions in the heuristic space instead of the "plain" solution space. In other words, hyper heuristics are a search method in which several heuristics are combined and adapted. The difference between meta-heuristics and hyper-heuristics is that hyper-heuristics seek to find a generally applicable methodology instead of solving a particular problem instance.

Although other research in this area cannot be ignored, especially those based on systematic search, metaheuristic approaches proved that they are performing well on benchmark timetabling tests. Moreover, metaheuristics have become increasingly popular in automated timetabling practices by adapting dynamically to constraints and covering a wider variety of optimization problems.

In summary, hyper-heuristics consist of search methodologies aimed to operate on a higher abstraction level than optimisation techniques and traditional search methodologies [46]. One might say that this approach is one step further in comparison to meta-heuristics. Hyper-heuristics have the potential to give generalised solutions to timetabling as a whole. A numerous amount of studies paid attention to a hyper-heuristics approach [67,68] in which basic heuristics are combined with each other.

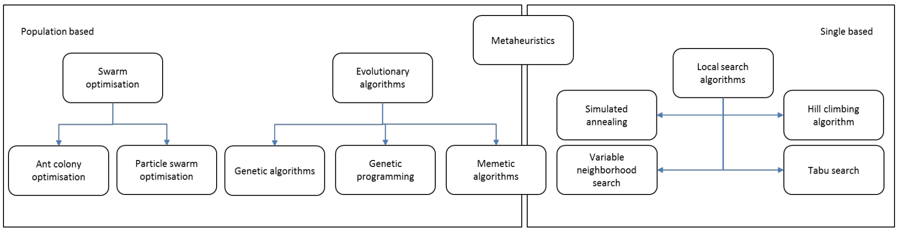

Fig. 3 An algorithm classification.

3.3.2 Timetabling application developments

Timetabling problems and methodologies can be complex, iterative and time consuming. Timetabling developers increasingly adopt a computer-based approach which enables institutions to automate tasks, finding (sub-) optimal solutions and work more efficiently. This section aims to outline and review relevant studies conducted throughout the last decades. The decision to distinct among decades is based on renowned surveys, conducted in the corresponding periods. It is also considered practical in both giving an overview and the possibility to describe developments in better detail. In this section timetabling applications are defined as the set of resources which function in a computerised environment to enhance timetabling practices.

Up to 1980. One of the first applications on a computer was developed by Gunzenhauser and Junginger (1964) [29]. They tested an algorithm combined with simple heuristics on a mainframe computer. However, the resulting timetable was certainly not optimal and needed modification by hand. In 1980, Schmidt and Strohlein (1980) [30] provided an annotated bibliography in which early techniques and system implementations were discussed. Most of these systems were based on graph colouring and recursive exchange operations in which partial timetables were extended.

1981–1990. The application of computational timetabling was still not widely accepted in the mid 80s. Most of the institutions did not have microcomputers available and the ruling thought about being scheduled by a machine caused resistance [30]. De Werra (1985) [31] proposed graph-, network- and mathematical methods and how they could be used in timetabling programs of application. This study showed that certain requirements were not yet translated into constraints and included as ingredients in the various models. Ferland et al. [33] proposed a 0-1 mathematical model and implemented it on a microcomputer. The constraints, however, had to be relaxed because the computer was lacking memory space and computational power. Junginger (1986) [32] described various software applications implemented and elaborated on the underlying approaches, which were mostly based on direct heuristics. This research concerned institutions in Germany, where the techniques and tools discussed were of a state-of-the-art nature in that time. Remarkably, literature in this area in the period of 1970-1985 consists mainly of case studies which report specific examples of computerised registration (Sabin & Winter, 1986). This combination of case studies performed and the changing requirements of different institutions, made it difficult to produce standard computerised solutions. In the ensuing period of early 1985, a significant amount of institutions started to adopt the use of PCs and were able to use bigger data entries [34].

1991–2000. A study of Bardadym (1996) [35] pointed out various aspects of interactive timetabling for timetabling software. Bardadym elucidated that timetabling software is capable of the following: database corrections, use of spreadsheets and DBMS, using timetabling editors and making use of an object-based interface. The use of those features, however, was mostly restricted to prove timetables correctness. The use of meta-heuristics and interactive timetabling were seen as the new wave of computer-aided timetabling. Schaerf (1999) [28] illustrates this trend in a survey of automated timetabling in which the papers in the survey describe to a certain extent the implementation of timetabling software. The survey illustrated how modern heuristics, like evolutionary algorithms, seemed to outperform the traditional operational research methods. Institutions were now able to generate feasible timetables in an acceptable timeframe. However, there were still many cases in which the problem was computationally too hard. Moreover, Schaerf [28] argued the need for widely accepted benchmarks and a common formulation of the various timetabling problems. The absence of those elements caused that algorithms and software application programs could not be compared among each other. A significant number of software applications developed within this period was either a commercial product which meant it had lost the emphasis on algorithms and focused merely on the GUI, or it had been designed for a specific institution [6].

2000–2015. Recent state-of-the-art papers pay attention to problems and challenges featured in work over the last decades. More standardised benchmark datasets become available and researchers explore directions in which the timetabling problem is placed in a real world problem context [36,37]. Standardisation of timetabling benchmarks however, leads to circumstances in which practical real world application is not maintainable most of the time. In other words, benchmark sets are mainly generated by means of a standard set of constraints or constraints based on specific HEI characteristics. In both cases testing algorithms against each other is not feasible because of the lacking generally applicability of real world problems [5]. De Causmaecker et al. (2002) [38] discuss how the semantic web and components like XML, can be used in timetabling applications. In a study of Chand (2005) [40] the adaptation of relational databases and the modelling of timetabling data is reviewed. Ranson & Ahmadi (2007) [41] reviewed the limitations of existing timetabling languages and standards and proposed a modern flexible language- independent timetabling model which can be adopted in timetabling applications. There is an increasing number of models that are used in the Timetabling competitions. Precisely these competitions gave rise to much research. Especially the international timetabling competitions (ITC) concern higher education, and had several tracks to apply to different institutions: Curriculum-Based Course Timetabling (CB CTT) and Post-Course Enrolment Timetabling (PE CTT). ITC 3 was aimed at secondary schools but is considered much richer in terms of constraints.

It becomes clear that timetabling applications are provided with most modern tools, technologies and techniques [43]. However, a study conducted by Pillay (2014) [42] discussed that there still exists a gap between academia and industry. While academia tend to develop intelligent and profound methods to solve timetabling problems, industry appears to develop and design an easy to use interactive tool that aims to meet the needs of teaching and administration staff. Once industry has a productive timetabling application, they stop implementing the latest research on timetabling in their software. Most timetabling applications nowadays may have a nicer user interface than say 20 years ago, but still use timetabling algorithms that stem from the beginning of their software production, somewhere in the late 80s or 90s from last century. This might be related to the fact that insufficient effort on the side of application development has been undertaken to translate real world situations into the constraints that have been identified in the format for the benchmark sets. Bridging this gap between the latest timetabling research and the implemented algorithms in timetabling applications can produce robust, efficient and to a certain extent general, timetabling applications in which the most modern heuristic approaches for timetabling problems are combined with the benefits of an easy to use timetabling application.

4 Characteristics of HEIs

HEIs are under growing pressure to deliver a student-central academic climate in which timetabling practices are fuelled by individual preferences [6]. Literature covering timetabling developments alone is not sufficient for satisfying those demands. The operational process of timetabling is embedded in specific institutions and must therefore connect to structural preferences held by these institutions. This results in HEIs influencing the way timetabling applications are adopted by means of their characteristics. Defining these characteristics of HEIs, in turn, is interrelated with (cross-) national ideologies and legislations which origins can be found in governmental influences and national systems of higher education [86]. In order to research the gap between theory and practice in greater depths, literature is reviewed concerning characteristics like knowledge levels, shared values and goals, organisational structure and current trends of governance in HEIs.

4.1 Governance of HEIs

Higher education encompasses a process of creating knowledge for enhancing employability and stimulating innovation where learning opportunities are made available through various institutions. HEIs are mostly integrated in a dynamic environment which is controlled and regulated by social, political, economic and institutional aspects (Scott, 2001). This regulation is translated in governance and describes to a certain extent how an HEI is organised and managed. Investigating HE governance supports the search to identify characteristics of HEIs because governance is always present in an HEI [76]. Governance embraces the determination of values inside HEIs, resource allocation and missions. The identity and formed culture of each HEI is shaped by legislations of HE governance. Nonetheless, the extensive notion of governance makes it difficult to categorise the structure of various systems in which HEIs are incorporated. Besides this, practices of HE systems and HE governance are still predominantly shaped at national level [46]. A significant amount of research has been dedicated to national and cross- national analysis of HE systems and HEIs, explaining trends and characteristics [48,49].

Rising competitive pressures, demographic and economic developments as effects of globalisation and internationalisation stimulated HE governance to reform [47]. A study conducted by Dobbins et al. (2011), proposed three ideal-type models of HE governance in which contemporary policy developments are reflected in: (1) in the state-centred model, HEIs are seen as state operated institutions. The state is heavily influencing internal matters like HEIs-business relations, quality assurance and efficiency. Education and research ought to contribute to industrial and technological competitiveness. (2) HEIs as a self-governing community is a model based on strong state-university partnership that is governed by assumptions of corporatism and collective agreement. (3) The third model is of a market-oriented nature. HEIs are seen as economic enterprises in local or global markets [76] and offer academic services to students. The aim is to bolster the choice of students in order to enhance quality and diversity of services offered. It is argued that those types are hybridised with each other in various countries.

4.2 Structure of HEIs

In the early 1960s, most European countries placed emphasis on diversification of HE systems. Structures like binary (two)-type and multi-type were more likely to emerge. Those systems had to function as multipurpose, specialised HE. However, some countries continued to use a unitary system in which, for example, universities were the only kind of institutional type [50]. In the late 1970s HE systems were increasingly paying attention to informal structural aspects like, quality assurance, excellence, job prosperity of graduates and reputation of the institution selves. In the ensuing period, as of the late 1980s, the different kinds of institutional types of HE and diversification in programmes were no longer that relevant [53]. However, the occurrence of multi-type structures was likely to persist in various countries [51,52]. A study conducted by Teichler (2006) [80] discussed why a vast amount of changes in structural developments in HE systems were notable: this has been explained by a number of conceptual frameworks. (1) The expansion and diversification of HE systems lead to a more diverse need of students, moreover, he described an (2) "academic drift" of institutions in order to stabilise themselves and increase status. Finally, he identified a (3) cyclical trend caused by reoccurring events like dropouts, for example. As a result of this cyclical trend, diversification among HEIs is reduced or either different HE types are subjected to segmentation. Around the late 1990s, the tendency arose to make HE systems more similar across Europe. The Bologna process, proposed in 1999, tends to harmonise HE systems throughout Europe in order to ensure compatible degree structures, equal academic qualifications and enhancing the attractiveness of foreign students to study in Europe [54]. Those developments have to foster for structural convergence of HE systems in Europe. Making a more generalised view of characteristics in HEIs, which are embedded in HE systems, more admissible. While various aspects proposed in the Bologna process already have been implemented, there still is not a wide framework on a structural level for HE systems which makes up for exceptions.

4.3 Nationalisation and globalisation of Higher Education

Altbach (2015) [46] elaborates in his study on the commodification of HE. He identifies a trend in which HE is increasingly seen as a commodity, which can be purchased by a consumer in order to build a "skill set". This skill set can be used in the marketplace and can be bought from HEIs. Commodification of HE implicates the marketing of knowledge products like, advanced training and bolstering of a highly skilled workforce. Two aspects which are interrelated with this are globalisation and internationalisation. Internationalisation of HEIs is mainly focused on fostering global learning experience, attracting overseas students and delivering national programmes abroad. This approach allows for situations in which the time and place dimension is merely less dependent whereas the focus on mobility is becoming more important in the learning process. Countries from all over the world move towards the internationalisation of HE. Such countries are opening their doors for foreign universities and programmes, are regulating foreign providers, are marketing national educational products and countries in Europe are harmonising their divergent HE systems as an implication of the Bologna process. Internationalisation and globalisation are intertwined [61]. Globalisation of HE embraces the more advanced information and communication technology, the emergence of a world-wide knowledge network as well as other influences beyond the control of HEIs [24]. In recent literature, HEIs are adapting newer IT practices to a greater extent [73]. Through the use of internet, programs can be offered at foreign universities. As IT becomes more sophisticated, distant learning or blended learning is becoming more wide spread (in combination with traditional learning). Blended learning is defined as the combination of traditional face-to-face education and technology mediated instruction [78]. A significant amount of research has been dedicated to the adoption and implementation of blended learning practices. Through the adoption of blended learning, students from different courses can participate in particular blended learning classes. It thus addresses some logistics changes that strengthens the need for a more flexible timetabling process. Another distant learning aspect is the rising topic on Massive Online Open Courses (MOOCs). They can be seen as scalable offerings of online courses which extend existing online learning approaches [79]. MOOCs have the possibility for freeing resources for HEIs in order to reduce costs and enhance space optimisation strategies, because participants are not bound to any location. Conclusions based on recent literature reflect that the emergence of MOOCs also accounts for structural changes and challenges in HEIs. Such kind of challenges in the field of timetabling in which questions like time-zone- and (fraudulent-free) examination planning arise. Concluding, MOOCs influence to a certain extent the allocation of resources, which encompasses timetabling practices.

4.4 Recent developments in HEIs

More and more external influences shape the policy, goals and characteristics of HEIs. The emergence of global rankings among HEIs is seen as a powerful stimulus for competitive thrive. HEIs are being constantly compared in a national and international context [72]. Even more in the setting of national competition: this global referencing caused that the institutional identity of the individual HEIs is becoming less important than the national identity of HEIs [61]. This is in accordance with the study of Teichler (2006) [80]: most institutions aim to stabilise themselves and tend to attain a higher status by comparing themselves to the most successful HEIs based on such rankings. Comparison in this manner caused many institutions making changes in policy and strategy, which is driven by the norm promoted by ranking. Students associate those global rankings with education quality and opportunities for a career. So it is evident that students play a key role in these policy decisions.

The student-as-consumer model has become increasingly prevalent. Many HEIs have begun to adopt customer-based models for students [69, 70]. Emergence of marketing plans, marketing promotions by institutions and assessing students experiences as effectiveness of HE, are examples of such models. Seeing students as customers of HE encompasses societal needs and norms. Moreover, expectations of the labour market also influence the student-customer-based model, because it is indirectly related to the societal needs incorporated by students.

In addition, student-teacher partnership collaboration is increasingly elaborated on in the last decade. This collaboration defines, and tries to understand, the role of both student and teacher in student learning [70]. Within this partnership, insights with reference to this relation student-teacher are collected. Furthermore, collaborations also aim to study and design teaching and learning together. Hence, this trend makes up for certain changes in structures and planning processes, like timetabling, in HEIs. To foster such developments in a more demand driven education structure, a flexible process of planning is essential. In this sense, the partnership must be harmonised in order to support a flexible environment between students and the HEIs. Direct implications are smaller-scale education, a shorter learning circle and more teacher FTEs [7].

5 Timetabling in HEIs

HEIs are in the last several decades subjected to both external and internal influences. This caused that particular HEIs are performing different roles. They are expected to meet demands from local, national and global pressures and ought to perform applied research, working with public sectors, local communities and having intertwined relationships with businesses [81]. Both government and society are setting demands for HEIs and there is in available literature a growing competition noticeable between individual HEIs [46,47, 49]. Hence, those institutions have to cope with such external forces, but above all, fulfilling the students expectations. The lecture aspect of HE in the institutions is steadily evolving from a traditional teacher-centred didactic style to a more interactive-centred style [82]. On the other hand, personal developments of students are fostered in a short-cyclic and smaller scale educational setting. Nevertheless, it is utmost evident that the process of efficiently allocating resources in HEIs is in a constantly moving field. Timetabling in HE has to deal with ever decreasing resources and is focused on delivering a feasible set of solutions in which the amount of variables, representing real-world applications, is constantly rising too [83].

5.1 Timetabling applications

Researchers in the field of HE timetabling acknowledge that timetabling solutions are diverse and institution-specific. The literature review conducted on characteristics of HEIs confirms and illustrates those diversifications between institutions. From the early 1960s onward, an increasing amount of timetabling applications and algorithms for HE have been developed in order to bolster the dynamic environment of HEIs in which those aspects are being implemented [31]. Within this period, different meta-, hybrid- and hyper-algorithms are modelled and proposed in papers aiming to be more generally applicable than most implementations [84]. As a result, the amount of papers steadily rose in which feasible automated timetabling solutions are proposed. This eventually led to a burgeoning focus on checking reliability of results claimed in papers on a benchmark application. Therefore, more online solving facilities emerged that encompass multiple instances of real-world problems of timetabling in

HEIs. Researchers are nowadays capable of generally checking their solutions due to more enhanced and comprehensive benchmark sets. This is in favour of the design of automated timetables and eases the process of fine tuning algorithms of multiple heuristics to solve hard search problems.

Furthermore, we identify that a wide scale of heuristic algorithms for timetabling problems already laid important groundwork: an increasing number of state-of-the- art research builds on this and aims to find the most suitable methods or sequence of heuristic algorithms to account for specific timetabling problems rather than finding solutions for the search problem itself [67, 68].

5.2 5.2 Timetabling at HEIs

In the last several years research aimed for a more enhanced and comprehensive search for optimisation solutions. Educational models are dynamic and subjected to change. Recently, a shift from a traditional to an interactive approach in which a demand driven model is more prevalent. This led to many researchers from all over the world developing timetabling software, but a vast amount of papers that were written about the software had their criticism on the fact that a standard benchmark instance was still lacking [26, 28, 85]. This paper shows, however, that a world- covering benchmark is not yet feasible. There are too many requirements and constraints that have to be taken into account, because many HE systems are still implemented on national level. There are aspiring ideas that are fostering for convergence of HE systems by means of the Bologna process, for example. This does not imply that a generally applicable timetabling solution or software application is not attainable in the near future. The emergent research that aims to search for the most suitable methods in order to solve timetabling problems is predominantly found in the field of hyper-heuristics. Based on the conducted literature review, it remains questionable whether contemporary state-of-the-art optimisation solutions are already being used in timetabling applications in HEIs. Furthermore, it is remarkable that researchers are following a substantially equal pattern regarding the developments of timetabling solutions in HEIs. The literature acknowledges various timetabling problems and proposes a new or enhanced model to cope with it. This model is explained and justified. Subsequently, the researchers test their proposal against several benchmark instances and discuss limitations. The actual implementation of these models in software applications, however, is often not described. In accordance with the study of Pillay (2014) [42] as described in section 3.3.2 timetabling applications developments, there still exists a gap between research and industry. To what extent do timetabling applications implemented in HEIs catch up with newer timetabling solutions in order to fulfil the demands of a particular HE system? The ensuing section is dedicated to conclude on this.

6 Conclusions and discussion

This research provided a review on timetabling developments. We subdivided trends and developments of timetabling in (a) timetabling algorithm developments and (b) timetabling application developments. A lot of research has been conducted in those fields and this resulted in an increase of more advanced algorithms for timetabling solutions. This is illustrated by means of particular timeslots in a chronology. Over time, the most state-of-the-art algorithms have focused on selecting suitable methods in order to provide for the optimal solution, rather than hybridising new algorithms. A considerable amount of papers identified the need for a standardised benchmark that covers multi-instances in order to test such advancements in optimisation solutions.

In the first part of the review on characteristics of HEIs we analysed literature about regulations and the way HEIs are being organised and managed. Institutions in HE are subject to external influences and pressures of the environment and this illustrates that HE systems are still predominantly shaped at national level. Furthermore, the rising competitive pressures in HE caused changes in the field of the provision of services and the process of planning.

The last decades the tendency arose to converge different HE systems in which composing a more general applicable timetable solution would become more admissible. However, it is evident that there are still various mutual differences among HEIs. Literature illustrated to what extent practices of nationalisation and globalisation affect timetabling in HEIs. More sophisticated communication technologies enhanced the use of blended learning practices and the adaptation of MOOCs, which resulted in freeing up resources and different space utilisation approaches for HEIs. Finally, the review encompassed identification of recent developments in HEIs. This paper identified that timetabling applications must offer flexible services to a greater extent. This is due to the emergence of global rankings, a prevailing student- as-consumer model and a dynamic demand-driven environment which implicated smaller-scale education in HEIs. Combining research on developments in timetabling and characteristics of HEIs gave us valuable insights in timetabling in HEIs. HEIs must cope with governmental, economic and institutional influences which eventually results in space-optimisation pressures. In order to keep up with these demands, the increasingly complex timetabling problems have to be solved by state-of-the-art optimisation solutions.

As we are concluding on the main research question, we identify a certain disparity between the theory and practice. Research within the field of HE timetabling is following a somewhat clear-cut pattern, and in particular research in algorithms. Literature in this field seems to lack attention on real implementation of optimisation solutions in timetabling applications. This implicates that timetabling applications comprise only a limited amount of state-of-the-art research in timetabling solutions, leading to a gap of 20 years or more between state-of-the-art algorithms in research and the implemented algorithms in timetabling software. This is unfortunate and results in unused opportunities for both researchers and institutions of HE. However, is this accountable to the prevailing fine-tuning on specific requirements instances, or the fact that it is not regarded as a top trend in information technology according to Gartner (2015) [8]? Perhaps it is about time to align academia and industry.

7 Future research

This article has not given a concrete approach towards aligning research and implementation. Successful implementations can align software engineering with algorithmic strength borrowed from research in the PATAT community as well as in the metaheuristic and constraint processing communities. But such a state-of-the- art system that can timetable a complete university is rare, especially when satisfaction of the users is measured.

The research model can be enhanced with additional literature and situational methods in order to do a more profound claim on gap analysis for example. Studies conducted by McCollum (2006) [5] and Pillay (2014) [42] identified such gaps and it would be very valuable to investigate in further detail whether some have been tightened.

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