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Analysis of classification systems for the built environment: Historical perspective, comprehensive review and discussion

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ABSTRACT

Research into the organisation of building project information began to bear fruit in the 1950s when the first classification system for the construction industry was introduced. Driven by the growing use of digital tools and technologies and by the first publication of ISO 12006-2 in 2001, this research topic has become incredibly popular in recent years. However, the absence of accurate historical traceability in the literature makes it difficult to understand the origin and evolution of the most prominent classification systems. The aim of this paper is to provide a comprehensive review of selected commonly used classification systems published in the last seven decades, delving into those developed in Sweden, the UK and the USA/Canada. Furthermore, the latest classification system launched by each of these countries (CoClass, Uniclass 2015 and OmniClass®, respectively) has been chosen to analyse, compare and discuss its strengths and weaknesses. The results of this research show that there is no consensus on the use of a common international classification system for the built environment. Although organisations worldwide are working diligently towards an internationally accepted standard classifier, the use of national classification systems still prevails. The main gaps to be bridged in this area are discussed in the paper and can be summarised as follows: (i) barriers are found to classify construction elements of residential buildings in a consistent, unambiguous and standardised manner, (ii) commonly used classification systems are designed so that the information required is acquired during the design and construction stages, and (iii) further work is needed to address the challenges of properly classifying construction elements at the operation and maintenance stage.

1. Introduction

Over the past decades, construction industry professionals have been striving to better document and organise building project information to facilitate communication and enhance information exchange [1–3]. In this regard, there is widespread agreement that a classification framework is essential for a coherent reference for the description, assessment, analysis and monitoring of buildings during their life cycle [4–7]. The historical classification approach focused on the needs of the early stages of the life cycle from primarily an economic assessment of building alternatives viewpoint: (i) concept and definition, and (ii) design and development. Such

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classification strategy was also identified as being helpful in the subsequent stages and was consequently extended to (iii) construction, installation and commissioning, (iv) operation and maintenance, (v) mid-life upgrading or life extension, and (vi) decommissioning and disposal.

Classifying items is a common technique characterised by the systematic organisation of content, which humans use to deal with the complexity of the real world [8]. A classification system, or "common language" [9], allows people to communicate on issues by providing sets of concepts that contribute to reducing the complexity of the subject to a level that is manageable for its users [8]. A common language is required in all communication, especially when large amounts of information are transferred between different persons. In this regard, a fundamental requirement for transmitting information is that the actors speak the same language, i.e., use the same designations and concepts [7]. In classification systems, terms are established, and knowledge is systematised into an appropriate structure. This methodology enables the knowledge of a particular field to be accessible to a broad audience beyond the specialists directly involved in the field [8]. On this subject, it seems clear that the development and deployment of classification systems for the construction industry will be a long process and, along the way, will have to face many challenges until they are widely used. However, the advantages of the classification systems in terms of standardisation and efficiency can only be obtained if it is used by many professionals [11].

Over the last seventy years, several national classification systems have been developed for the construction industry worldwide. Given the international attention they have attracted, it is important to point out the following ones: *Samarbetskommittén för Byggnadsfrågor* (SfB) [1], *Byggandets Samordning AB* (BSAB) [7] and CoClass [10] in Sweden; CI/SfB [11], Uniclass [12], Uniclass 2 [13] and Uniclass 2015 [14] in the United Kingdom (UK); and, UNIFORMAT, MasterFormat® [15], UNIFORMAT II [5,16], UniFormat® [4] and OmniClass® [17] in the United States of America (USA)/Canada; all of them are explained in detail in Section 3. Fig. 1 depicts the periods of use of these classification systems in Sweden, the UK and the USA/Canada. As illustrated therein, the earliest known classification system, SfB, was introduced in 1950, and since then, efforts to update and improve existing systems have not ceased. The lack of a globally recognised system which is internationally used in the construction industry indicates the complexity of designing a suitable building classification system.

Due to the urge for guidance on how to use standards in the field of information classification in the construction industry, since 1988, the International Organization for Standardization (ISO), through its ISO/TC 59/SC 13 Technical Committee on "Organization of information in the processes of design, manufacture and construction", has been working on the development of a prospective standard for provisional application. As a result, ISO/TR 14177 was published in 1994 as a technical report prepared to provide [18].

- The basis for a better flow of information during the creation and use of facilities,
- Guidelines for the organisation of industry information.

Its provisional application made it possible to gather information and experience on its use in practice in the years following its publication. Based on this preliminary experience, the Technical Committee referred to above and now focused on the "Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM)", developed the International Standard ISO 12006-2. This part of ISO 12006 was first published in 2001 when there was still little international standardisation of classification systems for the construction industry. This first edition is currently withdrawn and has been replaced by the second edition published in 2015 [19]. The purpose of ISO 12006-2 is twofold: (i) facilitate the exchange of information between applications throughout the life cycle of construction works (building and civil engineering), and (ii) define a framework for the development of built environment classification systems. ISO 12006-2 identifies a set of recommended classification table headers for a variety of information object classes, and it is intended to be utilised by organisations developing these systems and tables. However, it does not provide a complete operational classification system nor the contents of the tables (it only provides examples). The application of this second part of ISO 12006 for the development of local classification tables will facilitate the

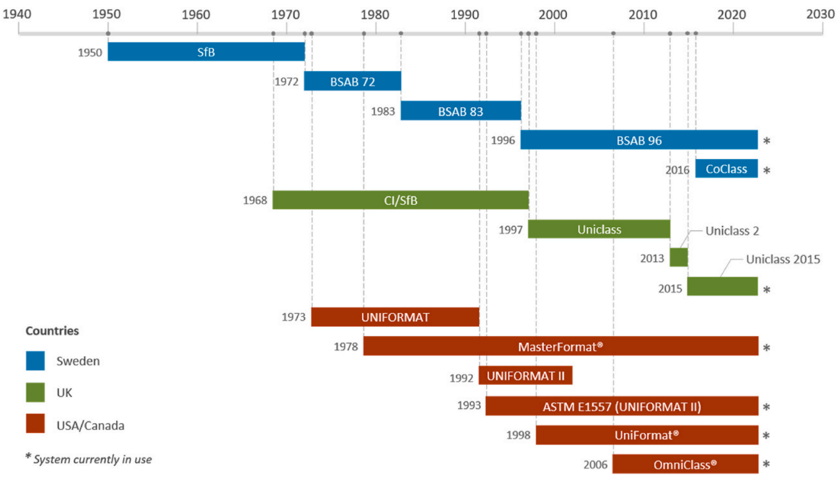

Fig. 1. Timeline of the classification systems analysed from Sweden, the UK and the USA/Canada.

harmonisation between them, even though there may be variations in some particular items/contents to meet local needs. Therefore, the emergence of this international standard plays a crucial role in the development of future classification systems, providing a common framework for classification.

Building Information Modelling (BIM) has established itself as a valuable process facilitator for modern Architecture, Engineering and Construction (AEC). It is specially intended to enable a more integrated design and construction process, which translates into better quality buildings at lower cost and shorter project duration. The observed trends reveal the potential and influence that BIM will have on the construction industry in the coming years [20]. Consequently, (i) existing classification systems are rapidly evolving to be adopted and used in BIM tools and methods, and (ii) new specialised standards in the organisation and digitalisation of information are emerging. In particular, ISO 19650-1:2018 [21], which focuses on information management about buildings and civil engineering works when using BIM, provides recommendations for information management, including exchanging, recording, versioning and organising, and it is planned to be used by all those involved in the asset life cycle. Concerning the requirements to ensure the information quality, ISO 19650-1 states that (i) the classification of objects must comply with the principles of ISO 12006-2, and (ii) the information of objects must comply with ISO 12006-3 to allow the exchange of objects. This third part of ISO 12006 [22] specifies a taxonomy model that allows referencing classification systems, information, object and process models within a common framework.

The term “classification system” is widely used in the building sector, particularly to refer to how non-graphic information is organised in digital tools. Nowadays, BIM implementation continues to be prioritised in the design, development and construction stages. This indirectly implies that the classification systems currently in use are designed so that construction project information is added from the outset. In fact, a well-known report on national specification systems considered that the phases of the construction process in which the systems are used were: (i) inception stage, (ii) design stage, and (iii) production stage; and that these three stages would be repeated throughout the asset life cycle. In addition, it stated that the information produced during the construction process would be used for facility management [23]. Unfortunately, such information is not always available for existing buildings, so the limitations of on-site data collection should be considered.

Although classification systems can be applied to general scenarios in the construction industry, this work is primarily concerned with their suitability for residential buildings. To illustrate the importance of such assets, according to the data from the last census round carried out in 2011 by the Spanish National Statistics Institute [24], in Spain, 9,730,999 buildings were designed mainly or exclusively for dwellings (at least 50% of their properties are dwellings). This plethora of existing housing stock is currently in the operational and maintenance stage within its life cycle. It requires regular inspections, repairs, enhancements and replacements, among other activities. In this case, it is evident that a standardised classification system for residential buildings would be beneficial for collecting, managing and exchanging information in an efficient and harmonised manner.

There is very limited published literature that delves into the origin, evolution, current situation and specific usability/applicability of the classification systems most commonly employed at the international level. The vast majority of existing works focus on describing the features of a particular system [25–28] or comparing the structure and content of a set of classification systems [29–38], but without providing an overall assessment of the differences and similarities between them, and their potential applicability to specific stages of the life cycle of the built environment. Moreover, the lack of accurate historical traceability in the literature makes it difficult to understand the need for its creation, the main changes that have marked its evolution and the relation/dependence between the available classification systems. To address the above-mentioned deficiencies, this paper aims to (i) present a comprehensive review of commonly used classification systems developed and utilised in different regions of the world over the past decades, (ii) analyse the strengths and weaknesses of the three classification systems most widely used at present (CoClass, Uniclass 2015 and OmniClass®), and (iii) identify potential knowledge gaps to facilitate the design of suitable classification systems for residential buildings during the operation and maintenance stage.

The remainder of the paper is organised as follows. The methodology adopted for the systematic literature review is presented first in Section 2. Next, an accurate review of the literature on classification systems developed in Sweden, the UK and the USA/Canada, as well as an overview of well-known systems developed in other regions of the world is provided in Section 3. The most popular

Table 1
List of references analysing and mentioning the different classification systems.

Country	System	Analysed	Mentioned
Sweden	BSAB	[31,32,38]	[26,28,30–32,35,37,38,40]
	CoClass	[26,35,37]	[26,35–37,40,41]
	SfB	[32]	[28,30–33,35,38]
UK	Uniclass 2015	[25,27,29,33,35–37]	[25–27,29,33,35–37,40,41]
	Uniclass	[25,27,30,32–34]	[25,27,28,30–35,42]
	CI/SfB	[29,32,34]	[27–34,42]
	CAWS	[29,32]	[29,30,32,34,42]
	Uniclass 2	[29]	[29,30,33,35]
USA/Canada	OmniClass®	[25,29,30,32–35,42,43]	[25,27–30,32–38,40–43]
	UniFormat®	[30,33,34,42–44]	[30,33,36,37,40–44]
	MasterFormat®	[30,32,33,42,44]	[26,30,32–34,36,37,40–44]
Finland	Talo	[43]	[28,30,31,36–38,40–43]
Denmark	CCS	[35,37]	[26,35–37,40,41]
	DBK	[28,38]	[28,30,35,38,40]
Netherlands	STABU LexiCon	[31,32,42]	[31,32,41,42]

classification systems are then analysed, compared and discussed in Section 4. Finally, the work is concluded, research gaps are identified, and suggestions for future work are presented.

2. Research methodology

Based on the recommendations of Palmatier et al. [39] in defining the different types and approaches of review papers, this domain-based review paper aims to comprehensively locate, synthesise and discuss the existing literature on selected classification systems for the built environment. The systematic literature review presented focuses on (i) describing and analysing the evolution of past and present classification systems and (ii) identifying knowledge gaps and best practices useful to guide future research in the area of building engineering. The main self-imposed constraint at the information-gathering stage, especially regarding the classification systems themselves, has been to gather as much material as possible from primary sources, i.e., organisations directly involved in the specific subject to be analysed. For this purpose, the information sources consulted include journal articles, conference articles, books, technical reports, standards, official websites and personal communications.

Following the literature review, Table 1 lists the authors who refer to the different classification systems to identify those which are best known and used. The references are grouped by country and sorted (from highest to lowest), first, according to the number of times they have been analysed (in relation to their characteristics, tables or history) and, secondly, mentioned (cited in the text). Note that systems not analysed by one of them or mentioned only in a reference have been excluded because of their low degree of representativeness. As introduced in Section 1, according to the data presented in Table 1 and illustrated in Fig. 2, the classification systems most referred to in the reviewed literature were developed in Sweden, the UK and the USA/Canada.

A large number of classification systems (and other related documents) gathered from Sweden, the UK, and the USA/Canada motivated the elaboration of a thoroughly historical investigation, detailed enough to facilitate its comprehension and traceability from its origins to the present day. In this regard, the charts depicted in Section 3 are based on the information found in the carefully-collected list of consulted sources. The authors have tried to be as rigorous and precise as possible. However, the lack of some publicly available information may potentially result in partially missing data. The inclusion criterion for selecting the rest of the countries to be reviewed in this paper has been the following: (i) the classification systems developed in these countries have been mentioned and/or analysed in the revised literature, (ii) those countries need to be participating members of the international technical committee ISO/TC 59/SC 13 [45], which is directly responsible for ISO 12006-2, and (iii) in order to have a broader approach, priority will be given to countries whose geographical location is not very close to other regions already analysed in the paper.

The method adopted for retrieving the most relevant articles on this work is based on the search items corresponding to “title” OR “abstract” OR “keywords”, which have been transversally specified as (“classification”) AND (“system”) AND (“building” OR “construction”) AND (“information”) AND (“element” OR “object” OR “class”). The search for journal and conference articles was carried out in the Scopus and Google Scholar databases. Given that the first edition of ISO 12006-2 was published in 2001, the sample selection was limited to references from 2000 onwards. On the other hand, the search for books, technical reports, standards and official websites was conducted through search engines with no time limit imposed, as the objective was to obtain information from first-hand (original) documentation. In contrast to other papers, relevant non-English literature was also reviewed and analysed.

3. Literature review

This section is mainly devoted to accurately describing the most relevant knowledge in the history of classification systems developed in Sweden, the UK and the USA/Canada. In addition, an overview of (i) national systems emerging in other regions (Denmark, Australia, Finland and Spain) and (ii) the recent initiative to adopt a common international construction classification system will be presented for further analysis and discussion.

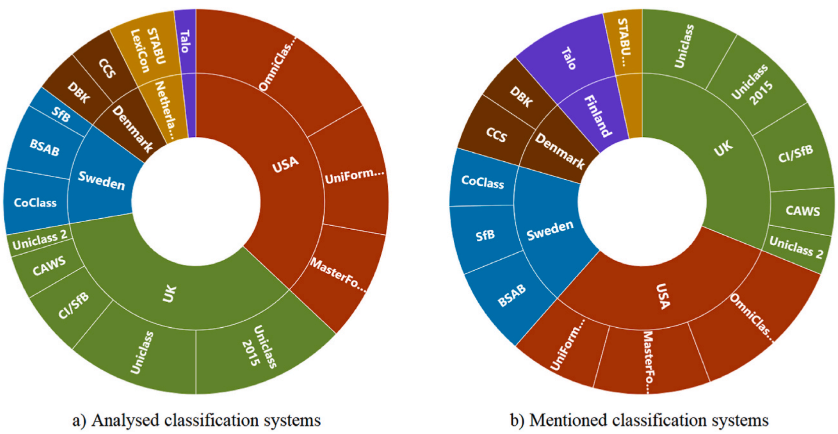

Fig. 2. Breakdown of the times in which classification systems (grouped by country of origin) were analysed (a) and mentioned (b) in the reviewed literature.

3.1. Classification systems developed in Sweden

To guide this subsection dedicated to Sweden, the chronology of published classification systems and other related documents is presented in Fig. 3. Based on the available public information and personal communications, it has been possible to identify for each classification system: (i) the first publication, (ii) the last publication (and if it is still in use or not), and (iii) the different revisions in the event that they were released. For scheduled revisions, the periodicity has also been specified. All the information summarised in this chart will be analysed and discussed in detail below.

The first approach to the creation of an information classification system was introduced in Sweden in the 1930s. In the late 1940s, the Building Cooperation Committee *(Samarbetskommittén för Byggnadsfrågor)* was founded, the so-called SfB Committee, composed of representatives of the 37 leading organisations in the construction industry. The SfB Committee sought, among other issues, to harmonise building standards across the country, modernise construction agreements and create better product information [7]. Nobody knew then that it would become the most famous Swedish Committee for its pioneering contribution to the development of classification systems.

In the autumn of 1945, research work began on what would later become AMA *(Allmän Material och Arbetsbeskrivning)*, literally, the General Material and Work Specification. One of the first texts to appear in the context of AMA, ByggAMA, was first published in the spring of 1950 and became a reference publication to describe construction work. ByggAMA intended to provide a general regulation for the quality of the product and the labour force, i.e. information on 'how' work should be done, rather than describing 'what' should be done, which should be clear in the description of the building [46]. Thus, AMA first provided a Swedish standard for construction descriptions, making the work simpler and more rational for descriptors. The texts represented good practice and were generally accepted in the sector, so AMA became a reference publication. The work was carried out with government funds within the SfB Committee [46,47].

As well as developing the AMA, the first classification system for the construction industry in Sweden and worldwide, known internationally as the SfB system [7], was presented in 1948 [47]. The Swedish architect Lars Magnus Giertz, technical secretary and head of the secretariat of the SfB Committee [46], was considered the main responsible for the invention of the SfB classification system [9], which was originally developed for the classification and coding of the ByggAMA standard description [48]. It can be deduced that the "SfB" system took its name from the initials of the Swedish Committee *(Samarbetskommittén för Byggnadsfrågor)*, which initially produced it [9]. The SfB Committee first published the SfB system in 1950. From its first publication until the late sixties, the SfB system was used in AMA publications.

The use of the SfB system in leading publications led to its gradual acceptance in Sweden and its widespread use as a standard method of filing documents in architectural offices. It quickly spread from Sweden to other Scandinavian countries (and elsewhere). The system was officially adopted in Hungary, Yugoslavia and the United Kingdom [1]. The SfB system was progressively attracting international attention. In fact, the Swedish Construction Service *(Svensk Byggtjänst)* actively participated in the development of a standard framework for classification within ISO in the development of the standard framework for classification, ISO 12006-2 [7]. Proof of its international impact over time is that the ISO standard 12006-2 was inspired by SfB and, in turn, most of the current classification systems for the built environment, such as OmniClass® (USA/Canada) and Uniclass (UK) – to be explained in more detail below – are based on this standard [47].

In its basic form, the SfB was considered one of the first faceted systems comprising three facets (or parts of the code) and the SfB notations were obtained by combining the symbols of the following three tables [1].

- Table I: Functional elements (indicated by numbers in square brackets),
- Table II: Construction (indicated by capital letters),
- Table III: Materials (indicated by lower case letters and subdivided by numbers).

Interest in classification systems became more acute in Europe around 1950, mainly as a result of rebuilding after World War II. Aware of this need, at the end of the 1950s, Sweden decided to transfer the copyright of the SfB system to the International Council for Building Research, Studies and Documentation (CIB). *Svensk Byggtjänst*, founded in 1934, took over the international administration of the SfB system on behalf of CIB through the so-called SfB office, which was transferred in the early 1970s to the Irish Construction

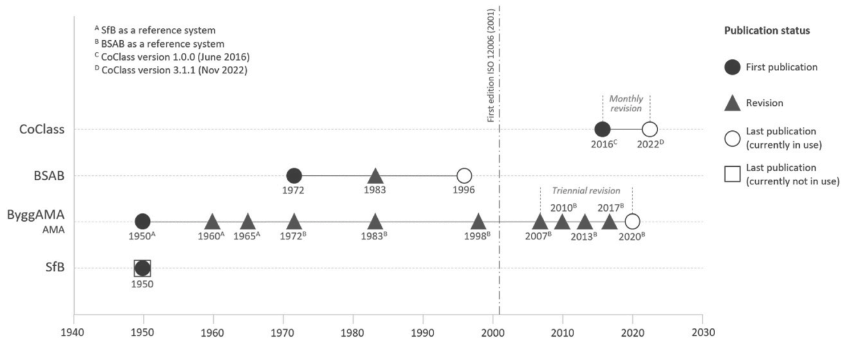

Fig. 3. Classification systems (and other related publications) in Sweden.

Research Institute in Dublin [7]. To ensure consistency in the application of the SfB system and also to avoid the development and application of new systems in other countries, a decision was taken to decree an international freeze on the tables until 1965. Although no review of the SfB system could be carried out until 1965, before that date, the structural defects would require a rather drastic overhaul. It was necessary to update the system to the new construction technology and to put it on a more solid basis as a classification system [1].

By the late 1940s, facility systems were simple and accounted for a small portion of the total construction cost. The situation gradually changed, and before the publication of AMA 72, publishers wanted a series of fully coordinated AMA technical publications for buildings and facilities, complemented by a publication of administrative regulations [7]. To implement this goal, the company *Byggandets Samordning AB*, shortly named BSAB, was formed in 1970 with some former editors of the AMA as owners [46]. After a lengthy investigation, it was concluded that a new system should be developed to give more room to the information structure on the basis of the SfB system, fully coordinated with AMA [7]. In this regard, BSAB developed a new classification system which considered both the views of the facility industry and the use of the system in a computer environment. The new system, called BSAB after its creators, was based mainly on the SfB system [46]. The first generation of the BSAB system was published in 1972 and replaced the SfB system in Sweden in the same year, almost immediately after the publication of AMA 72. From AMA 50 until before the publication of AMA 72, SfB had been used as a reference system in AMA books. Since the publication of AMA 72 until now, BSAB has been the reference system in AMA books. For product information, the SfB and BSAB systems were used in parallel; double coding was performed [7].

After an organisational negotiation, it was decided to merge BSAB and *Svensk Byggtjänst*, allowing BSAB to join *Svensk Byggtjänst*. The latter formally assumed responsibility for managing and developing the AMA and BSAB systems in July 1976 [46]. In connection with the development of AMA 83 initiated in 1979, the revision of the first generation of the BSAB system, BSAB 1972, was approved. First, the Product Table l “Constructions, assembled devices, etc.” had to be modified according to the AMA technical publications. Secondly, the review of the Product Table 2 “Facilities, components and installation systems,” was carried out step-by-step on different occasions. Finally, the most radical change in the part of facilities was the addition of a new main group 8 - Control and monitoring systems. As a result of this revision, the second generation of the BSAB system, BSAB 83, was published in 1983 [7]. AMA 83 was released just after BSAB 83 [46]. Until the publication of AMA 83, product information was generally requested in accordance with the SfB system. However, with the launch of BSAB 83, *Svensk Byggtjänst* recommended that product information be classified and coded according to the BSAB system. In addition, it also suggested the application of SfB codes, as this information was also sometimes used in other Nordic countries [7].

The board of directors of *Svensk Byggtjänst* decided to start the development of a new generation of AMA, AMA 98, in autumn 1993. One of the most significant changes was the incorporation of sections on maintenance, repairs and improvements to existing buildings. Since its inception, ByggAMA had been assigned to serve in general as a basis for the preparation of construction descriptions of new buildings [46]. This opened up the opportunity to extend its scope to the operation and maintenance stage. In 1996, the third and last generation of the BSAB system, BSAB 96, was launched. The structure of BSAB 96 was based on the work carried out between 1992 and 1994, which ended with extensive consultation with construction professionals. BSAB 96 was based on a holistic approach consisting of a set of collaboration tables, each expressing its specific aspect of information, but interacting with each other [7]. Since the two central tables in BSAB 96 (Components and production results) were developed in relation to AMA 98, both publications were coordinated. BSAB 96 was first published with established tables for building construction, and AMA 98 used BSAB 96 to classify and organise the contents of its books [7]. Although AMA was being revised to meet the needs of the construction industry, there was no timetable for updates until 2006, when it was decided that the different technical disciplines divided into AMA would be issued triennially [47]. The current AMA series, published in 2020, aims to serve as a basis for the production of technical descriptions and consists of five parts; four that are divided according to specific technical disciplines and a fifth that includes administrative regulations [49].

BSAB 96 represented a significant upgrade compared to BSAB 83, primarily due to its content (i) being more consistent across the different tables, and (ii) covering a greater part of the construction sector. In addition, many new tables were added, such as the Buildings and Spaces tables, so that the system could be used for a broader part of the construction and management processes. At the level of detail, the encoding changed from that of BSAB 83 [7]. An example of this can be seen visibly in the code positions of the main tables. These were structured with three letters before a point in BSAB 96, instead of a letter and number as it was in BSAB 83. This seemingly simple change was proposed as a result of extensive system development work with the aim of preparing BSAB 96 to meet future information needs [46]. A technological breakthrough was that BSAB 96 was first available in electronic format, including databases, which would help users to apply the tables effectively. This improvement provided new opportunities for efficient search and navigation at different levels, as it allowed the tables in various applications to be integrated with a simple updating process. In addition, it was considered of great importance to establish a set of specific rules for defining codes and headings in order to ensure a uniform and correct interpretation of the information encoded by the BSAB [7].

In mid-2014, the need for a substantial update of the BSAB 96 system was discussed, motivated in part by the development of the new version of ISO 12006-2:2015, which was adapted to consider developments in digital modelling. In order to have a broad representation of the construction sector and the Swedish administration, in the autumn of 2014, the Swedish Transport Administration *(Trafikverket)* initiated a collaboration with *Svensk Byggtjänst* and BIM Alliance Sweden *(BIM Alliance Sverige)* through a steering group. The main task of the group was to develop guidelines for preparing a new classification system for the built environment in Sweden and ensuring that relevant opinions from the whole industry were highlighted [10]. In January 2015, an extensive industry-wide development project called BSAB 2.0 was launched, resulting in the new CoClass classification system. In June 2016, CoClass version 1.0.0 was first published in connection with the public presentation of CoClass. The second major version (2.0.0) was released in September

2021. During this period, between version 1.0.0 and 2.0.0, a total of thirty-seven revisions were made, resulting in approximately one revised version per month, most of which simply contained small additions and corrections. The only major update between versions 1.34.0 and 2.0.0 consisted of the addition of alternative classes to the Structural supporting objects (UL). This group was supplemented by: Structural object in ground (UE), Vertical structural object (UF), Horizontal structural object (UG), Structural brace object (UH) and Structural arc object (UJ), on behalf of the Swedish Transport Administration, as an alternative to the use of UL. However, it is recommended that all others use the original UL classes (K. Eckerberg, personal communication, May 31, 2022).

CoClass was introduced as a system completely adapted to digital modelling, containing descriptions of objects, properties and activities throughout the life cycle for both buildings and installations. The aim from the outset was for CoClass to gradually replace BSAB 96. Although the intention was to translate CoClass completely into English before the end of 2016 [10], this task has not yet been completed; tables of *Produktionsresultat* (Work results) and *Egenskaper* (Activities) are not yet available in English [50]. CoClass was presented as a more comprehensive classification system that could be used throughout the life cycle. Reliable information on construction sites can facilitate the management of changes in the built environment. Therefore, the asset management application was an important driving force in the development of CoClass [10]. It was designed to handle information in a life-cycle perspective where standardised classes, terms and concepts create the conditions for an uninterrupted flow of information through all stages. This means an object has the same meaning for all actors throughout the life cycle [51]. CoClass introduces the concept of 'inherent function' as the function of an object, regardless of how the object is used. Therefore, the components are divided functionally without considering the chosen technical solution to fulfil its function. However, at the detailed level (components), there are many classes that are also defined by their construction or form. A class of components, therefore, is a set of objects characterised by the same inherent function [51].

In terms of scope, while BSAB 96 timidly introduced some tables related to objects (Construction entity, Built space, Construction elements and Production results), CoClass gave it a higher level of importance by significantly expanding the number of tables linked to objects. Currently, CoClass contains three types of tables: objects, properties and activities. In total, there are seven object tables that include the following sections: Construction complex (BX), Construction entity (BV), Space (UT), Work result (PR) and Construction element. The last category is broken down into three tables: Functional systems (FS), Constructive systems (KS) and Components (KO). This division of Construction elements into three independent tables, intentionally constructed with an open structure and no controlled connections between levels, provides flexible opportunities to classify buildings and facilities [10,50]. Although it is still possible to consult the two existing tables of the type activities, namely Activities (AK) and Maintenance Activities (FA), *Svensk Byggtjänst* recommends the preferential use of the AK table, which will possibly completely replace the FA table in the future (K. Eckerberg, personal communication, May 31, 2022).

The latest version released in November 2022 corresponds to CoClass version 3.1.1.[1] Currently, the management of CoClass continues to be carried out monthly (11 meetings/year). As a result of each meeting, a new update is published. However, today most are minor revisions and correspond to additions in the form of synonyms or class types (M. Malmkvist, personal communication, April 6, 2022). As far as BSAB is concerned (still in use), *Svensk Byggtjänst* will no longer update BSAB 96 tables significantly, except the Work Results table, because this table is shared with CoClass. The goal remains to archive BSAB 96 when CoClass is firmly implemented. CoClass is currently owned by the parties that initiated the BSAB 2.0 project to develop a redesigned Swedish classification system: *Trafikverket, Svensk Byggtjänst, BIM Alliance Sverige, Swedavia Airports, Trafikförvaltningen Stockholms läns landsting, Sveriges Kommuner och Regioner* and *Samverkansforum* [50]. *Svensk Byggtjänst* is the Chair of the reference group in charge of maintaining and developing industry practices for the application of CoClass in software [52].

3.2. Classification systems developed in the UK

As in the previous subsection, Fig. 4 introduces the classification systems and other related documents published in the UK. In addition to identifying the first and last publication, as well as the successive revisions, the following issues are added: (i) preliminary versions, (ii) legacy releases, and (iii) development releases. Please note that the last two were never published as a final version. A historical analysis of the most important facts which marked the origin and evolution of these classification systems follows the chart.

At the end of World War II in 1945, the authorities, architects and other construction stakeholders showed a keen concern about improving the construction process, reducing the time and cost of carrying out the work as much as possible [3]. The authorities responsible for the reconstruction of the destroyed areas, mainly in Belgium and France, convened the first International Conference on Building Documentation, which was held in the framework of the Paris International Exhibition on Housing and Building in the summer of 1947. During the Conference, the international need for documented information and the organisation of such information was highlighted. Furthermore, it was agreed that the format and classification of documents for filing should be unified and standardised. On the basis of the information sheets previously published in Finland, it was recommended that the format of the documents should be the A4 international size (297 × 210 mm) and, for classification purposes, a rectangular box (45 × 20 mm) should be printed in the upper right corner of the first page of each document. The box, which would serve to file each document, had to be divided into equal parts by a horizontal line; the bottom space would be occupied by the appropriate Universal Decimal Classification (UDC) number, and the top space was intended to indicate a simpler notation (not specified by the Conference). However, the problem of an international classification remained unsolved [1]. Years later, it would be agreed that the SfB classification should be indicated in the upper space of the box [3].

In November 1950, the Housing Subcommittee of the Economic Commission for Europe summoned a Conference of Building Research, which met in Geneva. The conclusion was reached that there was clear evidence of the need and potential usefulness of new

[1] To consult the latest updated CoClass tables, please visit the following link: https://coclass.byggtjanst.se/.

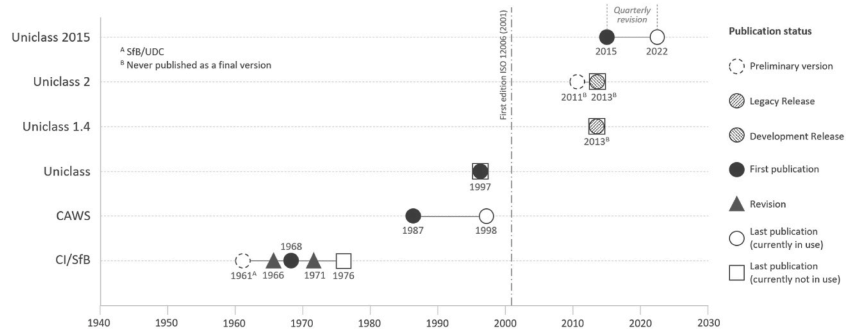

Fig. 4. Classification systems (and other related publications) in the UK.

arrangements to stimulate international research collaboration, and a small ad hoc group of experts, known as the BROC, was tasked with making detailed recommendations in this regard [53]. Simultaneously, the International Council for Building Documentation (CIBD) was formally set up in 1950 to standardise document classification and filing format [3,54]. In its beginnings, CIBD recommended to its partners to adopt the indexing language, UDC, for information exchange and recognised that greater uniformity in the work would be achieved by adopting a selection of numbers from the UDC. UDC is divided into ten main groups (0–9). These, in turn, are subdivided by the addition of new figures. In this way, each concept can be expressed in greater detail each time. Since 1895 it has evolved from the Dewey Decimal Classification and has been continuously improved by the Federation for Documentation (FID) [55]. In 1952 CIBD and FID established a joint committee to investigate the problems involved in the international classification and filing field [1,3,55]. This new committee, the International Building Classification Committee (IBCC), was the outcome of a conference of construction documentarians held in Copenhagen in October 1952 [3].

The BROC worked for over a year and finally produced a report in 1952 recommending that the creation of an entirely novel organisation should be avoided as far as possible. They proposed that the CIBD should be transformed into an organisation capable of dealing with both documentation and research, and that it should encompass three main areas of activity: (i) experimental research, (ii) studies and the application of the results of research, and (iii) documentation. This new organism be called CIB. CIB, which was expressly founded as a non-governmental organisation closely related to the construction industry, held its first General Assembly in June 1953 in Geneva with the main objective of approving its statutes [53]. That same year, IBCC assumed its responsibility and defined the following four main milestones to be achieved [1,3].

- Study and publish selected UDC numbers to be used for building classification,
- Study and publish the Swedish SfB filing system,
- Study other classification and filing systems in the field of building,
- Develop a standard method for classification and filing.

Regarding the first step, and in order to provide a simple and useful application of UDC in architectural and construction offices, "ABC: Abridged Building Classification" was published in 1954, an authorised abbreviated edition of UDC that included an alphabetical index and a more detailed explanation of the classification. ABC was published in several languages to facilitate the international coordination of terminology in the built environment [55]. Work on stage 2 began in 1955. The SfB system had been extensively studied by experts between 1949 and 1950 and was recommended by CIB as a suitable system for complementary use with UDC. Due to its popularity, in 1957, the IBCC studied and published a report on the system written by Egil Nicklin. The SfB Committee, composed of members who used the system, became responsible for future system development [1].

During stage 3, which began in 1957, a comparative study of the filing systems in use worldwide was carried out. Therefore, fifty-five systems were reviewed and compared, and the conclusion achieved by the study was that the two most useful systems in operation were UDC, due to its broad subject coverage, and SfB, due to its brevity, flexibility, and relevance to building practice. British architect Dargan Bullivant, probably considered a pioneer in the introduction of SfB in the UK [11], also came to the same conclusion [1]. In addition, Dargan Bullivant was a member of the IBCC working team that developed stage 4 and drew up the team report on filing according to a complementary SfB/UDC system. This system was published as a Building Filing Manual in the "Architects' Journal" on 17th September 1959 [1]. In the same year, the final reports were submitted jointly to the sixth plenary meeting of the IBCC held in Rotterdam. IBCC accepted the conclusions of the specialists that SfB was the most suitable system for the building industry and put forward the following recommendations [1,3]: (i) CIB was required to publish or promote the publication of the SfB system in various languages, (ii) SfB copyright had to be vested in CIB, (iii) the SfB tables were to be changed only on the advice of the IBCC, and (iv) SfB/UDC building filing manuals could be published nationally under the responsibility of CIB member institutes.

As far as Great Britain was concerned, copyright and responsibility for the administration, control and promotion of the SfB system rested with the Royal Institute of British Architects (RIBA), which was an associate member of the CIB. In agreement with the last recommendation listed above, in late 1961, the RIBA published the "SfB/UDC Building Filing Manual - Recommendations for standard practice in pre-classification and filing". The Manual, which contained the authorised English version of the original SfB system, was intended to help apply the system. Additional sections regarding the Swedish SfB system were added in the English version to make it comprehensive enough for use as a library classification. UDC numbers were also included to provide an alternative classification and add a level of detail that was missing from some SfB tables. It is worth noting that the SfB system was originally designed for the arrangement of specifications and bills of quantities and was made into a classification system for library use and wider applications by combining it with relevant sections of UDC numbers [1].

CIB, for its part, prepared a master list of headings for the arrangement and presentation of information used in the design, construction, operation, maintenance and repair stages of buildings and building services [56]. CIB composed and published a total of four editions of the Master List (in 1964, 1972, 1983 and 1993). As discussed above, changes to the original SfB system were controlled by the SfB Committee of the IBCC. An example of this was that both the IBCC and the RIBA guaranteed that no changes would be made to the tables in any of the local versions until at least 1965 [1]. Just a few years after the “SfB/UDC Building Filing Manual” was published, the RIBA found double coding (SfB + UDC) to be unnecessarily cumbersome and so proposed to develop a new classification system called CI/SfB to replace all relevant UDC tables [54]. In 1966 the RIBA issued a report by John Carter incorporating proposals for the revision of the SfB tables [1]. Indeed, some of them were well accepted by the IBCC and served as the basis for preparing CI/SfB, the UK version of the international SfB system. CI/SfB was developed and first published by RIBA in 1968 as a “Construction indexing manual”. Note that ‘CI’, which stands for Construction Indexing, was added before ‘SfB’ to distinguish it from the original Swedish tables that formed the basis. This same criterion was adopted by other countries, as will be seen later. The manual emphasises that no changes would be made to CI/SfB for two years after its publication in 1968, although the necessary corrections and advice would be provided [11].

CI/SfB was established as the most widely adopted classification system in the construction industry [2] to facilitate communication and information search. It introduced two significant changes with respect to its predecessor (SfB/UDC). At first, it included two new tables developed to suit UK needs: Table 0 (Built environment) built on the building type classification described in the “SfB/UDC Building Filing Manual”, and Table 4 (Activities and requirements) comprised the form and order of the “CIB Master List” of properties for building materials and products. Table 0 was linked to Table 1 (Elements), which was one of the SfB tables used in the UK since 1959. In this context, elements were considered “parts of buildings and site which form, in combination, the building types and spaces”. And secondly, CI/SfB excluded UDC numbers because surveys showed that UDC was being used in very few office libraries and was not recommended by the IBCC for use on temporary documents [11]. During the summer of 1968, the RIBA Council encouraged architects to use the CI/SfB tables to organise project drawings and other related documents. To explain how to use the new system in conjunction with other codes, the “Architects’ Journal” published a project information manual a year later. Finally, in 1971, RIBA published “CI/SfB Project Manual”, which described the organisation and arrangement of design team project information and documents. This edition included various sections that provided advice on applying CI/SfB-based data coordination methods to produce project documents such as drawings, schedules, specifications, and bills of quantities. In addition, a specific section focused on the definitions of the Elements table was presented for purposes related to building project information [9].

In 1987, the Construction Project Information Committee (CPIC), the committee responsible for providing best practice guidance on the content, form and preparation of the Construction Project Information (CPI) [57], introduced the Common Arrangement of Work Sections for building works (CAWS) as an alternative scheme for structuring building information [12]. Its development was the result of research that demonstrated that the quality of construction information was a very significant figure of merit of the quality of construction work. It was found that standardising the way that production information is generated and classified could help improve quality, but unfortunately, CI/SfB was not comprehensive enough to achieve this [58]. For this reason, CAWS was chosen as the UK’s authoritative classification system of work sections, designed especially to promote standardisation in the construction industry and detailed coordination between specifications and bills of quantities. In order to minimise variations and conflicts between documents or even within the same document, an important section was dedicated to the detailed definitions of working sections [59].

As far as Cl/SfB is concerned, it was last revised in 1976. When the SfB Agency in the UK reviewed the issue of its revision, they made the final decision that replacing it with a Unified Classification was better than modifying it [12]. The proposed new classification scheme for the construction industry was to be called Uniclass, developed primarily by the National Building Specification (NBS) on behalf of the CPIC and first published in 1997 by RIBA. Uniclass 1997 was conceived to replace and outperform CI/SfB for four main reasons: (i) to improve through international cooperative endeavour in the development of classification systems and tables, (ii) to introduce notation improvements to make codes easier to understand, (iii) to include modifications produced in the construction industry, including new types of building and aspects related to energy and the environment, and (iv) to incorporate CAWS in the new system to operate in an integrated manner [12]. Regarding the last point, CAWS corresponded to one of the fifteen tables of the Uniclass, specifically, Table J. In fact, CAWS was last updated in 1998 to bring it in line with Uniclass. In addition to making necessary changes as a result of advances in technology and practice, some new 360 work sections were added, and a much more itemised was included [59].

Uniclass introduced some novelties compared to its predecessor. Noteworthy is the new Table L – Construction products, based on the Electronic Product Information Cooperation (EPIC), a European system for grouping building products with the allocation of a single code to exchange product information across national borders [60], and part of Table C – Management to classify the building project information in consonance with the stage of the life cycle in which it is produced [12]. Despite its subtitle (Unified Classification), Uniclass was debated for not being considered an authentic unified classification system [61,62] because it was still a paper-based system and its tables were inconsistent. In fact, the tables differed from each other in many aspects, such as the encoding. For example, most tables used numeric encoding, but two of them used alphanumeric encoding, and although most of them adjusted to the maximum length of ten figures, some used double figures at some levels. Aside from the encoding issue, there was a lack of consistency in the scope as some tables covered building, infrastructure and process engineering, but others only covered one or two of those sectors, so the tables did not work well together [63] as an integrated system. On top of that, Uniclass was not fully aligned with ISO 12006-2.

The need to review Uniclass grew steadily, and in 2006, a Uniclass Working Group was established to address the issues noted above. The main reasons for the change were the urge to adapt the classification and specification to all construction sectors, together with the necessity for the classification to cover the description of works along the project schedule [64]. Several proposals for changes were received, including (i) a revised table for the Working sections, as a result of the combination of Table J (for buildings) and Table K (for civil engineering works), in order to provide a single table for all sectors and disciplines, and (ii) revision of the encoding to provide the extra room needed (e.g. Table J expanded from 2400 sections to 8000 sections) [27]. The Uniclass changeover process would not be easy, and it would take several years until it was defined as a unified classification system for the construction industry (buildings, landscape and infrastructure), suitable for managing information throughout the whole life cycle of an asset. During the transition process, Uniclass 1.4 – Legacy Release (never published as a final version) was launched by CPIC [65] with the purpose of providing a searchable tool (online version) on the classification tables for building and civil engineering combined. This tool was especially useful for CAD technicians and modellers who were developing ongoing projects that required Uniclass 1997 for reference. S. Delany, Head of Classification and Technical Author at NBS, stated that Uniclass 1.4 "was a recognition that it was difficult to separate buildings and linear assets on something like a railway. The building is the station but the rail corridor is a linear asset" (personal communication, March 1, 2022).

The next step toward a unified classification system was Uniclass 2 – Development Release, available in draft version since 2011 (never published as a final version), supplied again by CPIC [66]. Uniclass 2 proved to be a beta version of a new classification system needed to address the inconsistency and structure of the original document. It was intended to assist in information management throughout the construction industry and was a first attempt to explore a more cohesive classification (S. Delany, personal communication, March 1, 2022). At that time, it was suggested to stop the development and implementation of Uniclass 2 in the UK and move to the North American OmniClass® system (to be introduced later). However, it was decided that OmniClass® was not ideal for UK requirements for many reasons: UK/USA terminology problems, absence of the Complex and Systems table, inconsistent approach to table depth, and non-aligned tables, among others [67].

During the comment period of Uniclass 2, it was highlighted that Systems correspond to trades, which meant that the Systems sections, with their associated Products sections, replaced the traditional Work sections (in which Systems and Products are combined in one section). This was an indication that the Work Sections themselves would not be necessary [27]. Finally, it was decided not to invest further efforts in improving Uniclass 2, which was last reviewed in 2013. In mid-2015 and as part of a project funded by Innovate UK, NBS developed Uniclass 2015 [68], a unified classification system for built environment assets in compliance with ISO 12006-2, which allowed, for the first time, that buildings, landscapes, and infrastructure assets were classified under the same scheme [69,70]. It consisted of twelve tables that followed a hierarchical structure to allow project information to be defined at all scales, from the broadest level to the most detailed [14]. Designed with industry feedback on Uniclass 2 drafts in mind, Uniclass 2015 incorporated four main changes: (i) withdrawal of the Work Results table for being redundant, (ii) a consolidation item to make more room for infrastructure objects, (iii) a consolidation item to allow grouping of similar items, and (iv) bringing back a more familiar language from the construction industry to create classification headings [68]. Currently, the UK government requires that the classification of information for BIM projects be defined in accordance with Uniclass 2015 (the UK implementation of ISO 12006-2) [71].

NBS is responsible for keeping Uniclass 2015 up to date to ensure quality and accuracy in use are maintained and to safeguard that codes are flexible enough to accommodate evolving technologies or construction methods. Uniclass 2015 tables are currently updated quarterly[2] [69,70]. In the update programme published in July 2022, nine of the twelve tables have been modified, mainly to add new codes and corrections to existing classifications [72]. In addition to these regular updates, NBS is currently working on several new tables, including Properties and characteristics, Materials and Process activities. These new tables are expected to be available for public consultation by the end of this year and will be published at the end of the consultation (S. Delany, personal communication, April 12, 2022). Although NBS has always utilised the name "Uniclass 2015" to identify its origin and differentiate it from its predecessors, there is recently a change of trend by NBS towards simplicity, eliminating the year in the end. As a result, it is highly likely that future updates and publications will feature "Uniclass" instead of "Uniclass 2015".

3.3. Classification systems developed in the USA/Canada

In the same way as the study presented for Sweden and the UK, Fig. 5 summarises the classification systems and other related documents issued in the USA/Canada. Because of the similarities of most publications, nomenclatures have been written faithfully to their origins to avoid any confusion.

Due to their significant involvement in the development of standard formats for the USA and Canadian specifications, it is very convenient to start this subsection by introducing the main role of the Construction Specifications Institute (CSI) and the Construction Specifications Canada (CSC). In order of historical appearance, CSI was founded in the United States in 1948 as a national non-profit organisation. CSI is dedicated to improving the documentation, management and communication of building information through the development and dissemination of construction standards and formats [73,74]. Impressed by the CSI-led construction specification initiative, a similar association called CSC emerged in Canada soon after. CSC is a national multi-disciplinary non-profit organisation constituted in 1954 and is committed to the continuous development and delivery of quality education programs, certifications, publications, and services for the improvement of the construction community [75,76]. As for the administrative work of the US Federal Government, the General Services Administration (GSA) was established in 1949 to respond to the enormous backlog of construction needs stemming from an unprecedented expansion of the construction industry after World War II. The 1950s, 1960s and

[2] To consult and download the latest updated Uniclass 2015 tables, please visit the following link: https://uniclass.thenbs.com/download.

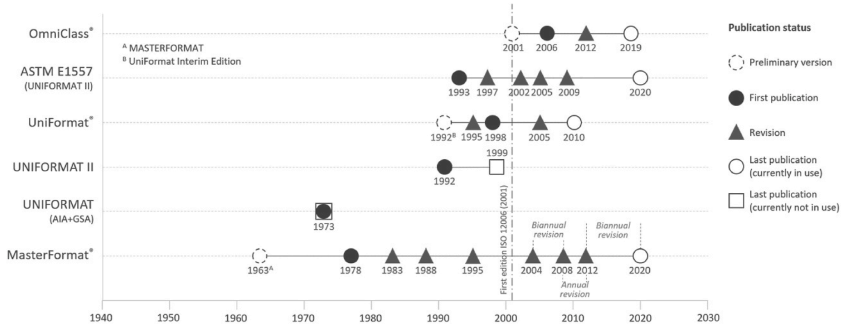

Fig. 5. Classification systems (and other related publications) in the USA/Canada.

1970s stood out as a period of extensive budget growth related to the construction of public buildings, coinciding with the second wave of Modernism, a time when architects were keen to explore advances in building technology [77].

To meet the organisational needs generated by the construction wave that emerged in the first half of the 1960s, a preliminary version of MasterFormat®, as it is now known, was first introduced in 1963 as a standard practice for organising specifications and was widely accepted in the United States and Canada. It was published as part of the "CSI Format for Construction Specifications", and it was later used as the basis for the development of the "Uniform System for Construction Specifications, Data Filing and Cost Accounting – Title One Buildings", finally published in 1966. More or less simultaneously, Canada took a similar line, and as a result of that endeavour, "The Building Construction Index (BCI)" was also published in 1966. Ultimately, the USA and Canadian formats were merged into a single format, introduced in 1972 as the "Uniform Construction Index (UCI)". It supplied the USA and Canada with a comprehensive framework for classifying and organising the information described in project manuals, along with providing a foundation for data filling and cost analysis [78].

In 1978, the revised UCI became the first edition of MasterFormat®, which was designed to address the urgent need for a national format for construction specifications, and was introduced to the construction industry by CSI as MP-2-1 and by CSC as Document004E. MasterFormat® 1978 Edition turned out to be a complete organisational format for construction project manuals [15]. MasterFormat® is a master list of numbers and titles for the construction industry that identify work results and construction practices, used primarily to organise project manuals and detailed cost information and to cross-reference data between drawing notations to specifications. Work results, as defined in MasterFormat®, are "permanent or temporary aspects of construction projects achieved in the production stage or by subsequent alteration, maintenance, or demolition processes, through the application of a particular skill or trade to construction resources". In other words, work results are the outcome in the facility after work has been concluded [15]. A classification system based on work results, such as MasterFormat®, is a logical format option when preparing detailed cost estimates. However, it would be inappropriate and time-consuming to use in the early stages of building projects. On the contrary, an elemental format based on building elements would provide less detailed and costly data but is useful enough for an economic analyst to evaluate building alternatives [5].

Concerning elemental formats, two organisational systems relevant to the construction sector were developed during the 1970s. In 1972, the American Institute of Architects (AIA) and its consultants, Hanscomb Roy Associates Inc., began working on MASTERCOST, a cost forecasting system designed to organise the documents related to cost control during the project's conceptual stage. It was initially intended to be a tool for collecting and sharing critical cost data on a large scale (from a wide variety of construction projects across the country). In this way, MASTERCOST would become the first national cost information repository. It was a framework for organising cost data in line with a system of major building elements (essential functional parts of the building), according to how an architect approaches a building project in the early stages of design. It also aimed to standardise cost vocabularies and definitions to minimise errors [79]. At about the same time, the GSA was developing another elemental format called UNIFORMAT, the details of which are not well known. Ultimately, AIA and GSA agreed on a consensus format that would be effectively called UNIFORMAT [5] and would be incorporated into AIA's practice on construction cost management and GSA's project estimating requirements. UNIFORMAT has never granted "standard" status or Federal recognition as an official elemental classification. However, it has underpinned most elemental formats used in the USA/Canada [6].

In 1989, the ASTM Subcommittee E06.81 on "Building Economics", which is under the jurisdiction of the ASTM Committee E06 on "Performance of Buildings", representing a broad range of the construction industry, embarked on a project to standardise the classification of building elements, partially based on the original UNIFORMAT. The new classification was named UNIFORMAT II to emphasise its ties to the first element-based classification in the USA/Canada [4]. The steam for applying UNIFORMAT II to specifications came that same year (1989), when CSI recommended that building projects in the schematic stage be more simply described by building elements rather than products. Elements, as defined in UNIFORMAT II, are "major components, common to most buildings, that usually perform a given function regardless of the design specification, construction method, or materials used (i.e. foundations, exterior walls, sprinkler systems, and lighting). The CSI recommendations were incorporated into FF/180 Practice – Preliminary Project Descriptions and Outline Specifications. Before that time, UNIFORMAT was primarily used for estimating and cost control [6].

In the first half of 1992, the ASTM Working Group and the Department of Defense (DoD) Tri-Service Committee on Work Breakdown Structure prepared two similar (but not identical) versions of an element-based format [6]. In August of that same year, the

National Institute of Standards and Technology (NIST), one of the oldest physical science laboratories in the USA, published "UNIFORMAT II: A Recommended Classification for Building Elements and Related Sitework" [5]. This report was the sixth in a series of NIST reports on recommended standards for applying economic evaluation methods to decision-making in the built environment. UNIFORMAT II 1992 Edition [5] was significantly influenced by the discussions and conclusions during the ASTM Working Group meetings. It was partly based on the original UNIFORMAT, and both formats could be considered elemental classifications. As noted above, this evolved version was designed to respond to requests from the building community to have a standard classification based on building elements instead of products or materials. The primary purpose of the publication was to gain consensus from the design and construction industry in preparation for writing an ASTM standard on UNIFORMAT II and to serve as the technical basis for its development. UNIFORMAT II differed from the original UNIFORMAT in several respects. While the original UNIFORMAT was developed specifically for the design stage estimates, UNIFORMAT II could be applied to all stages of a building's life cycle. UNIFORMAT II also considered a wider range of building types and was updated in accordance with current construction practices at the time [6].

The first edition of UniFormat®, as it is now known, was released by CSI that same year, 1992, as an Interim Edition for trial use and comment, based on the work of the ASTM Working Group and the DoD Tri-Service Committee on Work Breakdown Structure. The Interim Edition was published with the CSI Manual of Practice 1992 Edition and was coordinated with the MasterFormat® 1988 Edition [4]. Following the near-simultaneous publication of the NIST and CSI versions, ASTM voted and accepted UNIFORMAT II as a format for classifying building elements and related works. As a result, the ASTM Standard E1557 was approved and published in 1993 as a Standard Classification for Building Elements and Related Sitework – UNIFORMAT II, the classification that applied to physical elements only. Under ASTM Standard E1557, the purpose of using UNIFORMAT II was (i) to ensure consistency in the economic assessment of real estate projects over time and from project to project, and (ii) to improve reporting at all stages of construction [4,6]. This international standard is the direct responsibility of the ASTM Subcommittee E06.81 on Building Economics as one of the forerunners of the new classification system. Since its first publication in 1993, it has been revised in 1997, 2002, 2005 and 2009. The current edition corresponds to the 2009 revision, reapproved in 2020 [16].

Since the launch of the UniFormat® Interim Edition in 1992, CSI and CSC have been soliciting and collecting public comments and continued discussions with the ASTM Subcommittee E06.81 to determine the direction of future editions of ASTM Standard E1557 [4]. In 1995, CSI and CSC began revising the preliminary version of UniFormat® (i) to align the ASTM and CSI documents, (ii) to improve its usefulness in classifying information for emerging applications such as BIM, (iii) as well as to ensure the system was coordinated with MasterFormat® 1995 Edition [4]. This third revision of MasterFormat® underwent more extensive public review and coordination with industry users than any previous revision to date. It incorporated many minor revisions to numbers and titles and various changes to style and layout [78]. The first final version of UniFormat® was published in 1998 [17,33] as "A Uniform Classification of Construction Systems and Assemblies". UniFormat® was designed to be a layout of construction information based on the physical parts of a facility called functional elements, also known as systems and assemblies. These elements are characterised by the function they perform, without identifying the work results which make them up [4].

The UNIFORMAT II elemental building classification was reviewed by NIST and Concordia University staff, culminating in the UNIFORMAT II 1999 Edition [6], which was the seventh in a series of NIST reports on recommended standards for applying economic evaluation methods to decision-making in the built environment. This reviewed edition differed from the 1992 Edition in manifold ways. For instance, it provided alphanumeric designators for all elements, which met the ASTM UNIFORMAT II standard. It also introduced a standardised elemental cost summary format that helped users present their estimates in a concise, consistent and easily understandable manner [6]. There were three very clear goals for the new edition [6,80].

- Introduce a new fourth hierarchical level of definition to expand the three levels (used to date) envisaged in ASTM Standard E1557-97,
- Describe several applications of the UNIFORMAT II classification and the potential benefits of its use, especially for the preparation of specifications and estimates at the programming and design stages,
- Recommend a standardised format to summarise an elemental cost estimate using UNIFORMAT II.

Regarding the first point, it was clear that ASTM Standard E1557-97 needed to be revised to incorporate the proposed list of Level 4 sub-elements, which was partly based on that of the original UNIFORMAT and the Tri-Services TRACES Work Breakdown Structure (WBS). It is worth mentioning that Brian Bowen, President of Hanscomb, Inc. and co-author of UNIFORMAT II [5], contributed to the development of Level 4 [6]. UNIFORMAT II was intended to enable users to enter data in a consistent format and at any stage of the construction process. Therefore, it was not necessary to re-enter data in later stages [80].

In late 2001, when there was still little international standardisation of building classifications, the ISO published the first edition of ISO 12006-2 [81]. At that time, the construction industry realised that an information system needed to handle large amounts of data from different sources and formats. All such data and the relationships between them should be defined and structured in such a way that the information stored is consistent and reliable within and across applications. In that context, ISO 12006-2:2001 sought to provide an international framework to be applied for the development of future classification systems in the built environment. The OmniClass Construction Classification System (OCCS) Development Committee considered that following ISO 12006-2:2001 would promote the ability to map among classification systems developed worldwide. In September 2000, they held their inaugural meeting to address precisely this issue within the framework of a "Statement of Intent for Development of the Overall Construction Classification System". As a result of the meeting, nine guiding principles were defined to guide the development of the future comprehensive classification system for the construction industry, to be known as OmniClass®, which was meant to be an open and universally accessible standard [17].

R. Geren, the Subject Matter Expert at CSI, suggested that the publication of Uniclass in the UK might have influenced the creation of OmniClass® (personal communication, March 31, 2022). This possible influence would be reinforced by the fact that the OCCS Development Committee contacted the developers of Uniclass, who allowed them to use and adapt the structure and content of Uniclass for the development of OmniClass® [17]. In addition, it could be assumed that the start of development of ISO 12006 began on or before the start of OmniClass®, and the OCCS Committee implemented its principles during the review and comment period after the publication of the ISO standard in 2001 (R. Geren, personal communication, March 31, 2022). The first draft of OCCS was published in October 2001 for comment and review, but it was not until March 2006 that OmniClass® (Edition 1.0) was released as "A Strategy for Classifying the Built Environment" [17]. During this period of four and a half years of maturation, much work was done on the organisational structure and content of the draft version, with the aim of increasing the number of tables and refining their entries in the first edition of 2006 [17]. The second version of OmniClass® was available in 2012 and reaffirmed in 2019 as Edition 2.0 and Edition 2.1, respectively. In fact, version 2.1 was to confirm that version 2.0, released in 2012, was still applicable (R. Geren, personal communication, March 31, 2022). Solid proof of this is that eleven of the fifteen tables in the 2019 version are identical to those published in 2012, and there are no updated tables available beyond 2013.

From the very beginning, the OCCS Development Committee advocated using existing systems and compatible initiatives to avoid duplication of efforts. This would enable them to deal with areas where classification tables had not yet been developed or to harmonise existing approaches in a single table. Under this 're-use' principle, OmniClass® relied on other systems in use to form the basis of its tables. For instance, UniFormat® was the reference source for developing the content of Table 21 – Elements, MasterFormat® was for Table 22 – Work results and EPIC was for Table 23 – Products, although the latter was no longer updated [17]. Despite the fact that OmniClass® uses MasterFormat® and UniFormat® as reference sources, these will continue to exist as stand-alone systems with a particular application outside of OmniClass® [82]. OmniClass® provides a classification method for the entire built environment, with the extent and depth of coverage of construction types, throughout the life cycle of the facility. While it was developed with a North American focus, it may be used in other countries. CSI has acted as the OCCS Development Committee Secretariat since its first draft in 2001 and is responsible for keeping up to date and publishing the fifteen inter-related tables that represent different facets of construction information[3] [82]. Although CSI is the Secretariat, CSC is involved in the process. Indeed, it should be recalled that Table 21 and Table 22 are based on UniFormat® and MasterFormat®, respectively, and both are standards maintained jointly with CSC (R. Geren, personal communication, March 31, 2022).

With regard to MasterFormat® revisions, the 2004 Edition was considered the most relevant in the document's history. Among the most significant changes introduced in this edition was the adoption of a six-digit numbering system (arranged in three sets of matched numbers) instead of the well-known five-digit system (arranged in a single set of numbers) that had been in use since 1978. This increase in numbering length provided more flexibility and room for more subjects at each level, which resolved concerns about future expansion [83]. Another major expansion occurred in the number of Divisions, which was increased from sixteen to fifty. Finally, it should be noted that since this fourth edition, the titles have been revised to use terminology that more consistently reflects that MasterFormat® classifies work results and not products [84]. In order to review the content of UniFormat® and recommend future revisions and enhancements, a CSI/CSC UniFormat Task Team was established in 2005. Since then, it has been responsible for reviewing, maintaining and expanding its content to meet the current needs of the construction industry. Over the following five years, several workshops were held, and three document drafts were prepared. The UniFormat® 2010 Edition is the outcome of decisions taken in response to discussions and feedback received. This latest edition includes some titles changes, reorganisation of categories, update of MasterFormat® references to the MasterFormat® 2010 Edition and improvement of its usefulness for classification of information for new applications such as BIM [4].

Currently, UniFormat® 2010 Edition and MasterFormat® 2020 Edition are complementary organisational tools. First, UniFormat® is most commonly used in the early stages of building projects to organise the construction information around the physical parts of a facility according to its function, without even identifying technical solutions. Second, MasterFormat® is the primary vehicle for the organisation of commercial and institutional building specifications in North America. This is why it is appropriate to switch from UniFormat® to MasterFormat® to classify the physical elements at the time of project development when particular work results are selected [15]. OmniClass® 2019 Edition, on the other hand, provides a comprehensive classification structure designed to define the information generated throughout the building project life cycle and add it to a database or software. Although the year "2019" was mentioned in the title of the last published User's Guide, it should be noted that most of the tables were last updated in 2012. In OmniClass®, the information is collected and organised in a discrete and coordinated set of fifteen hierarchical tables [82]. CSI is the copyright holder of these three standards, UniFormat®, MasterFormat® and OmniClass®, as well as associated trademarks.

3.4. Overview of classification systems elsewhere

This subsection aims to collect the most relevant classification systems developed in Denmark, Australia, Finland and Spain, which are participating members of ISO/TC 59/SC 13. As previously noted, this technical committee is focused on the organisation and digitalisation of building information and is directly responsible for the development of international standards ISO 12006-2, ISO 12006-3, ISO 19650-1 and ISO 19650-2, all referenced in this paper. At the end, the recent initiative to use a common and universal classifier throughout the life cycle stages of construction entities will be highlighted.

[3] To consult and download the latest updated OmniClass® tables, please visit the following link: https://www.csiresources.org/standards/omniclass/standards-omniclass-about.

3.4.1. Denmark

The construction exhibition *Byggecentrum* was established in 1968 [85] and was the licensee of the SfB system in Denmark. Since its launch, the Danish version of the SfB system has been revised and updated several times. The last official and complete publication of the classification system was published in 1978 under the title SfB Building Materials Register *(SfB byggevare-registrering)*. Finally, a new (and latest) version known as BC/SfB-Building component *(BC/SfB-Bygningsdeltavle)* was published in 1988, which incorporated modifications mainly in the first system table and therefore differed from the international SfB version [86]. Despite efforts to implement the BC/SfB system in the Danish construction industry, in practice, the complete system has been underutilised, mainly due to insufficient updating of its structure and content. Limitations emerged as new materials, and construction systems appeared that required a higher level of detail. This often led to problems in consistently identifying the coding of construction products which limited their use to catalogues of construction products such as HFB rather than building processes [86,87].

Motivated by the government initiative known as Digital Construction *(Det Digitale Byggeri)* during the period 2003–2006, a classification project was prepared by BIPS *(byggeri, informationsteknologi, produktivitet, samarbejde)* in the Digital Foundation. The most important result of the project was the publication of the Danish Building Classification *(Dansk Bygge Klassifikation)* in 2006, known as DBK 2006, which was to succeed the BC/SfB system [88]. The intention was to form a common basis for the organisation and exchange of information in the construction industry [89], but it was considered more as a simple class identification than a classification system [28]. DBK 2006 consisted of eight complementary publications (mainly structure and classification tables), which provided a framework for classifying the built environment throughout its life cycle. Considering that the aim was to create a new national classification system that was also internationally compatible, the work carried out by standardisation organisations (e.g. ISO and IEC) was taken as a starting point [88]. DBK 2006 was introduced as the first system with a part-all mentality that differed from traditional classification tables by organising all parts of the building into a hierarchy where different building parts were, per definition, part of a larger whole. This meant that the parts of the building were organised differently according to the structural context of which they were part, i.e. the same construction element (e.g. insulation) acquired a different code depending on the part of the building of which it was part. As concluded later, a classification that depended on composition was technically inappropriate from an information technology perspective [89].

The Ministry of Housing and Regional Planning launched a competition in 2009 to recover from the lack of success of the DBK 2006 system [90]. That was the origin of the Cuneco Project that BIPS carried out between 2011 and 2015 with support from the EU and the Danish government [91]. Thus, the Cuneco Project focused on remedying the problems and deficiencies of the DBK 2006 system, creating a new and improved classification system based on the stability principle: the classification of parts of the building should be stable throughout the life cycle of the coded object. This meant that the split criteria should be 100% independent of the structural context in which they are included [89]. The Cuneco Classification System (hereinafter CCS) was first introduced in 2012 and, following the process of development, revision and public consultation, the first final version was published in 2014. The basis for the CCS classification were the international standards ISO 12006-2, IEC 81346-1 and IEC 81346-2 [89,91]. CCS provided the building and civil engineering sector with a common language and methods to achieve an unambiguous exchange of information throughout the construction process [92].

In order to create a unique and stable identification code for each object type, a combination of prefixes (special characters), classification codes (letters) and numbers (serial numbers) was used [89]. CCS provides a set of digital tools [93] such as classification tables, component specifications, an identification guide, a framework for information exchange and levels of information, among others. All these publications have been developed to help structure and manage information related to the built environment. One of the underlying ideas of CCS is that an object used in the construction industry, apart from being typically categorised by “classification”, can also be defined by its function through a selection of “properties” (e.g. lighting, ventilation, emergency exit). As a consequence, the classification and properties of an object define what function it has and what its characteristics are. Additionally, the “identification” can be added through “type-ID”, “product-ID”, and “location-ID” in order to define exactly which object is and where it is [94]. Through the scale of levels of information, it is possible to group information about the objects at each stage in which they appear, from the initial idea (level 1) until it is done (level 7) [92]. Currently, Molio (Construction Information Centre) emerged as a result of the merger of *Byggecentrum* and BIPS in 2016 and is responsible for maintaining and publishing the CCS tables. Most of the CCS Classification tables were last updated in 2020.[4]

3.4.2. Australia

NATSPEC is a national non-profit organisation founded in 1975, owned by the government and industry bodies, which aims to improve the quality of construction and productivity of the built environment through information leadership. Among its responsibilities is to keep the National Classification System up to date, thereby providing Work Sections for project specifications, which would correspond to the Work Results table proposed in ISO 12006-2:2015. System notation is hierarchical and consists of numerical codes which may contain up to four digits. The NATSPEC classification system[5] is the most widespread in Australia and is based on the predecessor classification system published in 1989 and developed by architect and planner Bryce Mortlock, considered the founder of NATSPEC [95]. In 2005, an amended version of the 1989 NATSPEC classification system was reintroduced when NATSPEC and Masterspec (from New Zealand) agreed to align their systems more closely [96]. Another significant change occurred in 2007 when a

[4] To consult and download the latest updated CCS tables, please visit the following link: https://anvisninger.molio.dk/gratis-vaerktojer/ccs_klassifikation.

[5] To consult and download the latest updated NATSPEC documents, please visit the following link: https://www.natspec.com.au/resources/national-classification-system.

significant number of new Work Sections were added due to the introduction of AUS-SPEC, the technical specification system for the life cycle management of minor infrastructure. However, it was never recognised as a comprehensive classification system for the Australian construction industry, such as Uniclass 2015 (UK) or OmniClass® (USA/Canada). Due to the increasing use of data-based applications (BIM), the urge for an information classification system became imperative [95].

Since Australia did not have its own system, it was necessary to decide which existing system should be adopted [97]. Surely everybody would agree that it is not an easy decision to make, and that is why NATSPEC has been analysing and comparing current classification systems for years from several points of view: availability, scope, structure, alignment, ongoing development, notation, etc. Although in their latest technical report [95], they do not end up positioning for any of them, it seems that, for the moment, the balance is leaning towards Uniclass 2015 [97]. This apparent preference can be contrasted with some examples of applications. First, industry experts, supported by NATSPEC, recommended that Transport for New South Wales (TfNSW) adopt Uniclass 2015. Following their recommendation, and after a thorough analysis of the current state and a comparative investigation of the classification systems available against ISO 12006-2:2015, TfNSW made the decision to choose Uniclass 2015 to enable Digital Engineering. Its role is not a mere user, but TfNSW is actively involved in the development of Uniclass 2015, providing detailed adaptations to support transport infrastructure assets [98]. Secondly, Austroads, the collective of the Australian and New Zealand transport agencies, recommended in 2018 to improve the structure and content of its Data Standard, not only to better serve road networks through the life cycle of assets but also to align it with other data standards. On this last point, it was concluded that the Austroads Data Standard should be aligned with buildingSMART IFCs and Uniclass 2015. Among the difficulties of adopting Uniclass 2015 is the absence of the Properties table, since it seems to be the main cause of gaps in the assignment of objects and properties of Austroads to Uniclass 2015. As long as the final Properties table is not available, Austroads must propose the objects it deems necessary to the NBS team running Uniclass 2015 so that it can take them into consideration [99].

3.4.3. Finland

In the early 1970s, the Finnish construction industry initiated a development programme aimed at more efficient use of electronic data processing through the building construction process. The purpose of the programme was to provide a harmonised nomenclature system to improve the exchange of information between the parties to the construction process. This project led to the creation of the first national classification system known as Building 70 (in Finnish *Talo 70*). The system has been regularly updated since its creation, making it possible to publish a revised version every decade. Consequently, the successive versions of the Finnish Building Classification System correspond to the following nomenclature: *Talo 70*, *Talo 80*, *Talo 90* and *Talo 2000*. Although Talo 70 and Talo 80 already included breakdowns of the building category, Talo 90 was the first to include a complete set of classification tables for spaces, building elements, work sections and different resources (construction products, labour and work equipment), with the aim of supporting typical Finnish construction practices [100]. Due to the fact that the system has not been renamed since 2000, *Talo 2000* (Building 2000) is the most recent publication of the Finnish Building Classification System.[6] Unfortunately, no information is available on the date of the first/last publication of *Talo 2000*, nor on the frequency of updates. Its classification tables cover Building elements, Services elements, Project-related tasks, Property management tasks, User tasks and Project provisions [101]. *Talo 2000* not only specifies a set of classification tables for grouping purposes but is also a tool that supports BIM procedures, cost estimation, design, production, planning and control, among other applications [102].

In contrast to general practice elsewhere, in Finland, specifications and cost estimates are based on building elements, the final products of construction activities [100,102]. This could be the reason why the Building elements classification table has been widely used in building specifications, bills of quantities, cost estimates and cost control [100]. Since building elements are designed according to the production classification, they will have to be divided into structural parts if several types of production work are required to produce a single building element [101]. The classification of building elements consists of pure physical building and service elements. In turn, the classification of elements consists of site, building (base building) and space (infill) elements [102]. Building Information Ltd. (*Rakennustieto Oy*) is currently responsible for providing updates to the *Talo 2000* nomenclatures. *Rakennustieto Oy* was founded in 1974 by the Building Information Foundation RST sr (*Rakennustietosäätiö RTS sr*) under the name Building Book Ltd. for its commercial operations, such as book publishing and exhibition of building products. The Foundation was established in 1972 when (i) the Finnish Association of Architects handed them the RT Building Information File (first published in 1942 to meet the needs of standardisation and guidance for reconstruction caused by World War II) and (ii) the Central Association of Construction Engineers ceded the Helsinki Building Centre, the second oldest building centre in the world, as the basic capital [103].

3.4.4. Spain

The use of a unified classification system for the construction sector in Spain is in its infancy. *Grup d'Usuaris BIM de Catalunya* (GuBIMCat), a BIM User Group of Catalonia (Spain), promoted the creation of GuBIMclass as a classification system for construction elements in the last decade. The collaborative work of GuBIMCat initiated the study of different international classification systems and took as its basis the work developed by *Infraestructures de la Generalitat de Catalunya, SAU* (Infraestructures.cat). Infraestructures.cat began to develop its base during 2014 as part of the round of follow-up meetings of the first BIM pilot tests they conducted. At the end of that year, Infraestructures.cat proposed to use the first table in building projects where BIM models were available; the utilisation of the table was not mandatory but served as an efficient strategy to receive suggestions and comments [104].

[6] To consult and download the latest updated *Talo 2000* nomenclatures, please visit the following link: https://login.rakennustieto.fi/index/tuotteet/nimikkeistot_21/talo2000.html.

Infraestructures.cat and GuBIMCat analysed the existing national and international classification systems and concluded that (i) there was no national reference that could be valid for the entire life cycle of a building project, and (ii) it was necessary to reformulate the Anglo-Saxon systems (UniFormat®, OmniClass®, Uniclass, etc.) to facilitate their use by the local companies. For a year, a working group assembled by GuBIMCat, named "Classifications", extended the existing system in Infraestructures.cat towards a new classification model to meet the needs of the Architecture, Engineering, Construction, and Operations (AECO) industry in Catalonia (Spain). According to its creators [104], the GuBIMclass system has the following characteristics: (i) the elements are classified in line with their main function and following their constructive sequence, (ii) it is independent of project life cycle stages and BIM uses, (iii) is easy to use, (iv) has a scalable coding, (v) maintains a certain homogeneity between chapters, and (vi) uses a common language. GuBIMclass currently consists of nine chapters related to building projects, but in the future, the system may also be extended to civil engineering projects. The use of GuBIMclass has gradually spread from Catalonia to other regions of Spain. A clear example can be found in national tender documents, which recommend (or even require) their use as a classification system for BIM objects. The latest version is GuBIMclass v.1.2, which was released in July 2017 and can be downloaded for free in Catalan and Spanish.[7] Although the GuBIMCat working group meets regularly, there is no timetable for updating the system.

3.4.5. International approach

As has been pointed out, there are currently many classification systems in the world, some of them in compliance with ISO 12006-2, although there does not seem to be an international agreement to use one or the other. At this point, other countries wishing to use a classification system may choose to create their own unique system or join together to create an international one. The initiative for the adoption of a common international construction classification system arose from Estonia's need to increase the digitalisation, as one of the measures proposed by the Ministry of Economic Affairs and Communications, in Estonian *Majandus-ja Kommunikatsiooniministeerium (MKM)*, in order to curb the low productivity growth of the construction sector. In June 2018, MKM announced a tender for "Developing of a unified classification system for the construction sector". Tallinn University of Technology (TUT) won the tender together with the team from Tallinn University of Applied Sciences and Building Centre of Estonian Construction Information Centre (ETF).

The main purpose of the work was to develop a common construction classification system for all construction entities (buildings and infrastructure), considering modern trends (BIM and digital construction), thus creating a unified and understandable language for the management of construction information throughout the life cycle of buildings [105]. The working group responsible for preparing the so-called Construction Classification International (CCI) system analysed and compared different classifiers widely used, such as CoClass, OmniClass®, Uniclass and CCS, and decided that there was nothing to gain in setting up a new Estonian system [106]. In September 2020, the Construction Classification International Collaboration (CCIC) was established by the Estonian Construction InformationFoundation and the Czech Standardization Agency with the support of Molio from Denmark. Shortly two more institutions joined: buildingSMART Poland and BIM Association Slovakia. CCIC, which owns the CCI classification system [105], is an international non-profit organisation that acts as an umbrella for all institutions interested in classifying the construction industry [107].

The CCI classification system, first published in 2020, was inspired by the CCS approach developed in Denmark. It should be clarified that it was initially expected to sign a cooperation agreement to develop an international classification system based on CoClass by mid-2020. However, the management of *Svensk Byggtjänst* and the owners of CoClass finally decided to completely exclude the international dimension of CoClass. In view of the reaction from Sweden and given that the CoClass developers relied on the Danish CCS system, it was decided to reorganise the activity and adopt the Danish CCS classification framework as a starting point for continuing the international cooperation already underway [105]. CCI complies with ISO 12006-2:2015 and the ISO/IEC 81346 series.

Given that the CCI had to be able to be used simultaneously by different countries, it was essential to establish common rules to reflect those differences. On that account, the components of the ISO 12006-2 model were divided into two key groups: (i) the main components, which are common to all partner countries, and (ii) the national components, which should be defined by each country. Creating a classification system for the built environment is a long process, and not all international tables are yet complete. To date, five core tables have been published: (i) construction entities, (ii) spaces, (iii) functional systems, (iv) technical systems, and (v) components. Note that the last three tables grouped define the "Construction element" concept. The sixth table on Complexes is currently in draft status, and according to J. Saar, Chair of the CCIC Board of Trustees, the Technical Committee hopes to finalise it soon, so a new revision of the core tables could be published before the end of 2022 (personal communication, July 7, 2022). Functional systems and Components tables connected to "Construction aid" are also available for download, although they are not yet fully completed, so they could be modified or upgraded. All these tables were last updated on October 4,2022.[8] The CCIC Technical Committee, composed of representatives of Czechia, Denmark, Estonia, Lithuania, Poland, Slovakia and Finland, is responsible for maintaining the CCI core tables, which are constantly updated [107]. At present, the content of the CCI tables mirrors the ISO/IEC 81346 series. Consequently, all uploaded versions are due to typographical corrections, not to incorporation of new classes or codes (R. Puust, personal communication, November 8, 2022).

The idea behind adopting a common international classifier is that each CCIC member state will be able to develop its own national classification system according to the CCI core tables. So far, three official national CCI systems have been published: CCI-EE in Estonia [108], CCI-DK in Denmark [109] (apart from the Danish CCS system), and CCI-CZ in Czechia [110]. In addition, Lithuania is in the

[7] To consult and download the latest updated GuBIMclass table, please visit the following link: http://gubimcat.blogspot.com/p/lobjectiu-ha-estat-obtenir-un-sistema_19.html.

[8] To consult and download the latest updated CCI tables, please visit the following link: https://cci-collaboration.org/.

process of developing CCI-LT (J. Saar, personal communication, July 7, 2022). It is important to highlight that the core tables correspond to the ISO/IEC 81346 series because it is supposed that the CCI can be used in all technical fields and industries (e.g. electricity, mechanics, energy, construction, etc.) to serve the whole society [106]. To date, four parts of this standard have been published. Part 1 specifies (i) general principles for the structuring of objects (both physical and non-physical) and (ii) rules on the formulation of unambiguous reference designations for objects in any system. A reference designation labelled on a component is crucial to finding information about that object among different types of documents [111]. Part 2 establishes classification schemes with defined object classes and associated letter codes (independent of how objects are used or applied in any design throughout the life cycle), intended primarily for reference designations [112]. Part 10 focuses on the field of power supply systems, being supplementary to the general principles specified in Part 1 [113]. Finally, Part 12 not only establishes rules for the structuring of systems and the formulation of reference designations but also provides classes for systems in the field of construction works and building services. Its implementation could therefore increase the efficiency and economy of such activities [114].

To briefly recapitulate the most relevant findings presented in this third section, Fig. 6 illustrates a mapping of the existing classification systems commonly used in each of the countries analysed in this comprehensive review. Note that the USA, Canada, the UK, Denmark, Sweden, Finland and Estonia are currently using classification systems based on ISO 12006-2:2015. On the other hand, Spain and Australia only have a national single classification table instead of a pure classification system, so it is impossible to fully comply with the international standard mentioned above. However, Australia has also documented successful experiences with Uniclass 2015.

4. Discussion

As a result of the comprehensive review of the literature on selected classification systems for the built environment, this section will highlight the convergences and coincidences between the most widely used systems today. Because of their long track record, CoClass (Sweden), Uniclass 2015 (UK) and OmniClass® (USA/Canada) are the best-known classification systems in the construction industry.

4.1. Comparison of currently most widespread classification systems

This subsection compares the three systems chosen (CoClass, Uniclass 2015 and OmniClass®) in terms of their general characteristics, the tables that compose them, and their design and structure.

4.1.1. General description of the classification systems analysed

While CoClass and Uniclass 2015 are the fruit of a complete overhaul of their predecessor systems, OmniClass® seems to have remained anchored in the past; it retains practically intact its initial structure, and two of its tables still come from previous systems (MasterFormat® and UniFormat®). As can be seen in Table 2, the three systems analysed are designed to classify the entire built environment over the life cycle and comply with the general classification framework recommended by ISO 12006-2:2015. However, CoClass differs from the rest in complying with the ISO/IEC 81346 series, which implies that the description of objects is constructed in

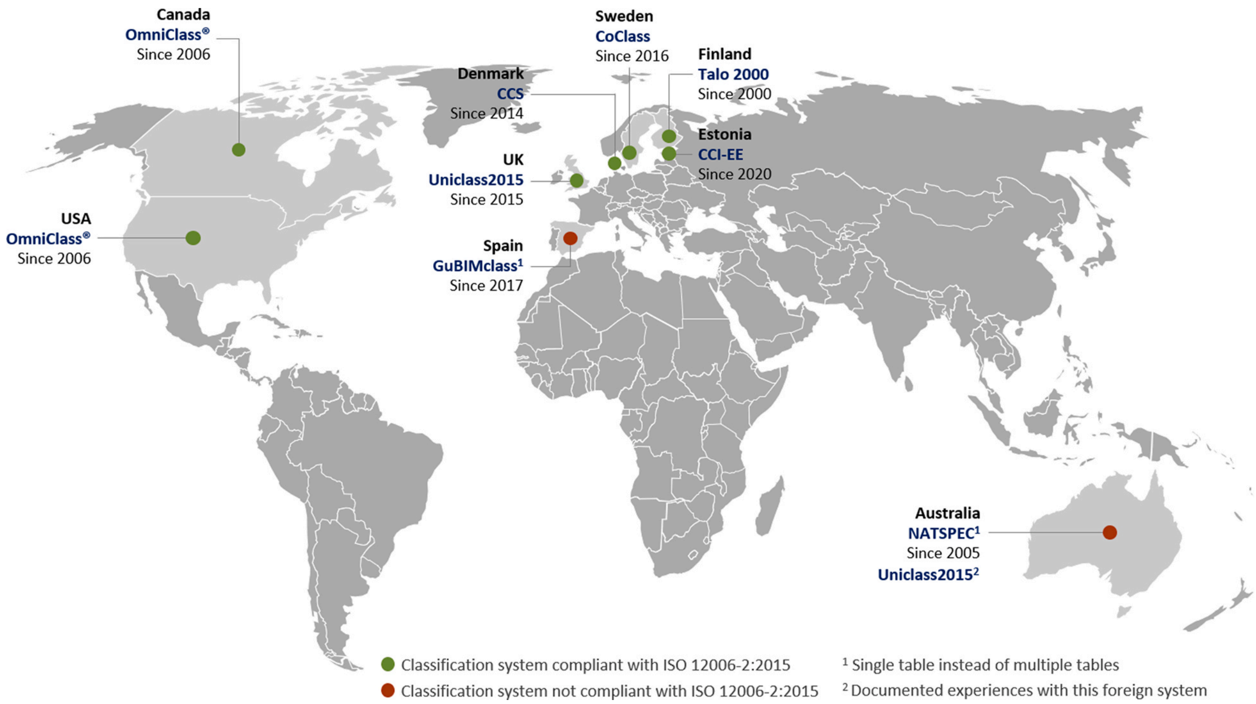

Fig. 6. Mapping of existing classification systems analysed.

Table 2
Description of currently most widespread classification systems.

	CoClass	Uniclass 2015	OmniClass®
Organisation	Svensk Byggtjänst	NBS Enterprises Ltd.	The Construction Specifications Institute, Inc. (CSI)
Country of origin	Sweden	UK	USA/Canada
Language	Swedish and English (partially)	English	English
First publication	2016	2015	2006
Last revision	2022	2022	2013 (partially)
Predecessor systems (year of the first publication)	SfB (1950) BSAB 72 (1972) BSAB 83 (1983) BSAB 96 (1996)	CI/SfB (1968) Uniclass (1997) Uniclass 2 (2013)	UNIFORMAT (1973) MasterFormat® (1978) UNIFORMAT II (1992) ASTM E1557 (1993) UniFormat® (1998)
Compliant with	ISO 12006-2:2015 IEC 81346-1:2022 IEC 81346-2:2019 ISO 81346-12:2018	ISO 12006-2:2015	ISO 12006-2:2015
Scope	Built environment	Built environment	Built environment
Coverage	Complete life cycle	Complete life cycle	Complete life cycle
Document/file format	Web service	Spreadsheet (.xlsx)	Spreadsheet (.xls) Portable (.pdf)
Open access	Partially (free version only gives access to the basic table view, and personal information is required)	Fully (personal information is required)	Non-open access (licence payment is required)
Source	byggtjanst.se/tjanster/coclass	uniclass.thenbs.com/	https://www.csiresources.org/standards/omniclass
Update frequency	Monthly	Quarterly	Unscheduled
Software	CoClass API	NBS BIM Toolkit	Crosswalk®

a composition structure according to the recommended rules for reference designations.

Regarding the ease of access to the different classifiers.

- CoClass offers a web service with a free version (CoClass Bas license) which gives access to a basic and limited view of the tables and a paid version (CoClass Studio license) that allows the complete view of the tables,
- Uniclass 2015 has a free browser and also provides the option to download the current and previous tables in Excel format (only identification with personal data is required),
- OmniClass® is not open access and license payment is required to download the tables in Excel and/or PDF format. This change was introduced recently, as until mid-2022, it was a completely free source.

Table 3
Tables of currently most widespread classification systems with reference to ISO 12006-2.

ISO 12006-2:2015		CoClass (Sweden)		Uniclass 2015 (UK)		OmniClass® (USA/Canada)	
Construction resource							
A.2	Construction information	–	–	FI	Form of information	36	Information
A.3	Construction products	–	–	Pr	Products	23	Products
				–	*Materials*	41	Materials
A.4	Construction agents	–	–	Ro	Roles	33	Disciplines
						34	Organisational roles
A.5	Construction aids	–	–	TE	Tools and Equipment	35	Tools
Construction process							
A.6	Management	–	–	PM	Project management (in part)	32	Services
A.7	Construction process	–	–	–	*Process activities*	31	Phases
Construction result							
A.8	Construction complexes	BX	Construction complex	Co	Complexes	–	–
A.9	Construction entities	BV	Construction entity	En	Entities	11	Construction entities by Function
						12	Construction entities by Form
A.10	Built spaces	UT	Space	SL	Spaces/locations	13	Spaces by Function
						14	Spaces by Form
A.11	Construction elements	FS	Functional systems	EF	Elements/functions	21	Elements (Uniformat®)
		KS	Constructive systems	Ss	Systems		
		KO	Components				
A.12	Work results	PR	Work result	Ss	Systems (in part)	22	Work Results (MasterFormat®)
				Pr	Products (in part)		
Construction property							
A.13	Construction properties	–	Properties	–	*Properties and characteristics*	49	Properties
(Other tables not included in ISO 12006-2:2015)							
		AK	Activities	Ac	Activities		
		FA	Maintenance activities	Zz	CAD		

The fact that CoClass (i) does not offer the possibility to download the tables in editable format, (ii) all the information is in Swedish by default, and some definitions in English do not correspond to the original version, (iii) not all tables are translated into English (Work results and Activities are missing), and (iv) having to deal with a slow browser, makes it challenging to use when compared to its two competitors. In contrast, it is the classification system that has a higher frequency of updating, practically monthly, unlike Uniclass 2015, which is quarterly and OmniClass®, which does not have an established schedule. There is no doubt that setting a frequency for updates is an urgent issue to be settled by the CSI to ensure the traceability and consistency of the OmniClass® development process. Bearing in mind that classification systems must constantly evolve to adapt to the growing needs of the construction sector, it is a matter of concern that the vast majority (73.3%) of its tables were last updated in 2012 and the rest in 2006 and 2013.

4.1.2. Tables of classification systems analysed with reference to ISO 12006-2

This part of the comparative analysis aims to evaluate the concordance between the tables of the three classifiers. The comparison compiled in Table 3 is organised by reference to those recommended by ISO 12006-2:2015, grouped into four categories: Construction resource, Construction process, Construction result and Construction property. First of all, CoClass seems to have the least matching tables, although it should be remembered that it also complies with the ISO/IEC 81346 series. Therefore, the classification approach must necessarily be different. In this regard, among all the tables available in CoClass, it is worth highlighting those related to the Construction elements. The levels of granularity underlying the classification criterion are described below. A Construction entity (Table BV) is an independent unit in the built environment (e.g., building) and usually consists of a set of Functional systems (Table FS) that each fulfils the main function. A Constructive system (Table KS) is a part of a Functional system with a particular sub-function and is used to describe functions and properties in more detail. In turn, a Constructive system consists of one or more Components (Table KO), which are the smallest functional units in the built environment. As will be illustrated in subsection 4.2, Construction elements are defined by the concatenation of the codes given in the tables FS, KS and KO.

The Uniclass 2015 classification system is one of the most dynamic currently, as it is in a continuous improvement process. In September 2022, twelve tables have been published, most of which are closely related to the ISO 12006-2:2015 recommendations, but others like Zz - CAD (introduced since the Uniclass 2 version) are totally genuine. At first glance, it is surprising that there is no specific table for the Work sections. The reason is that Systems typically correspond to trades that are executed using the corresponding Products. This combination would result in traditional Working sections, so it is not considered necessary to add another similar table. In fact, during the preparation of Uniclass 2015 (Uniclass 2 comment period), it was decided to withdraw the Work Results table, available so far, as it was deemed redundant [25,27,115]. Under this premise, it seems consistent to consider that Systems and Products tables can be partially equated to Table A.12 Work results in ISO 12006-2:2015. Another important factor to note is that the (i) Materials, (ii) Process activities, and (iii) Properties and characteristics tables have been marked in italics and without any identification code because they are currently under development by NBS. Presumably, they will be equivalent to the tables referred at the same level. However, such correspondence will need revision at the time of final publication.

Finally, OmniClass® was the first of the three systems to be released almost a decade ahead, but probably the one that has suffered the least structural changes in its fifteen tables. In fact, neither the numbers nor the headers of the tables have changed compared to Edition 1.0 launched in 2006. They have only grown in terms of content. That seemed to be the initial idea of the OCCS Development Committee; the tables initially presented as a Release state had to have such a good foundation that no changes were needed to their basic organisation [17]. Strangely, this is the only classifier that does not have a specific table for Construction complexes. The latest user's guide published in 2019 [82] suggests that Table 11 – Construction entities by Function, and Table 12 – Construction entities by Form, correspond to Table A.8 Construction complexes in ISO 12006-2:2015. However, these two tables are designed, as their own names indicate, to classify the Construction entities instead of providing a classification of the Construction complexes that allows

Table 4
Design and structure of currently most widespread classification systems.

	CoClass (Sweden)	Uniclass 2015 (UK)	OmniClass® (USA/Canada)
Structure of classification system	Enumerative (higher levels) and faceted (lower levels)	Faceted	Faceted
Structure of individual tables	Hierarchical, with a “top-down” approach	Hierarchical, with a “top-down” approach	Hierarchical, with a “top-down” approach
Number of tables	10	12	15
Maximum level of hierarchical nesting	3	4	7
Classification scheme (higher to the lower level)	Level 1 (class) Level 2 (sub-class) Level 3 (sub-sub class)	Level 1 (group) Level 2 (subgroup) Level 3 (section) Level 4 (object)	Level 1 Level 2 Level 3 Level 4 Level 5 *(some of them)* Level 6 *(some of them)* Level 7 *(some of them)*
Expandable structure	Not necessary. If the object of interest is not located, it shall be classified at a higher level.	Extra room is provided between existing codes to accommodate future additions.	Extra room is provided between existing codes to accommodate future additions.
Notation	Alphanumeric characters	Alphanumeric characters	Numeric characters
Coding example	B.AD.QQA030%F5	Ss_25_30_95_95	21-02 20 20 10

identifying each Construction entity that composes them. Tables 11 and 12 can be used independently or in a complementary way to classify Construction entities characterised by their function, i.e., their main purpose or use; or by their physical form. The same applies to Table 13 and Table 14 concerning Spaces, which are the basic units of the built environment delineated by physical or abstract boundaries. Whereas Table 13 classifies spaces by function (primary use), Table 14 focuses on their physical form, which can be a three-dimensional volume (e.g. room) or a two-dimensional surface (e.g. walkway).

4.1.3. Structure of the classification systems analysed

According to ISO 22274:2013 on "Systems to manage terminology, knowledge and content — Concept-related aspects for developing and internationalizing classification systems" [8], a classification system is considered as a systematic collection of classes (or sets of objects sharing the same characteristics) organised under a set of known rules, and in which objects can be grouped in conformity with the purpose of the classification. Classification systems should be carefully designed to avoid structures that do not provide the necessary information or that are too complicated and confusing for users, as this would make it difficult to unequivocally characterise objects. Taking this premise into account, Table 4 evaluates the classification systems studied based on selected factors to better understand how they have been designed and how their content is expressed.

ISO 22274:2013 identifies three main principles in terms of structuring any classification system: (i) enumerative, which attempts to list all possible topics within its defined area of applicability generally using hierarchies; (ii) faceted, allowing multiple classification assignment to an object, i.e., an object can be characterised by any combination of the classes from the facets; and (iii) enumerative and faceted, a combination of the two above approaches with an entry class [8]. The standard itself recognises that in many cases the latter structure is advantageous. In accordance with the structuring principles of IEC 81346-2:2019 and based on the best of our knowledge, CoClass uses a combination of enumerative and faceted classification. On the one hand, the higher levels of the classification system follow an enumerative approach (based on the inherent function) to narrow down the areas of applicability of the individual classes to a manageable size. On the other hand, the faceted approach is applied at the lower levels to clearly specify the nature of the concepts contained in the leaf classes of the classification system. As for the individual tables of the three classification systems, they all have a hierarchical structure consisting of a set of breakdown levels, from the top (large concepts) to the bottom (detailed elements). The number of tables and the maximum level of hierarchical nesting for each classification system are given in Table 4.

Possibly one of the most important distinctions regarding the degree of maturity and determination of classification systems is the fact that CoClass, in compliance with IEC 81346-2, considers its tables to be complete. This implies that non-specific identifications such as "others", "general", or "miscellaneous" do not appear in their tables as occurs in OmniClass® and, to a much lesser extent, in Uniclass 2015. Based on this argument, it appears reasonable that it is not necessary to expand the existing structure either. In case the object of interest is not found among the available coding, instead of creating it expressly, it shall be classified at a higher level. The other two classifiers provide gaps between existing codes to accommodate future additions without causing a disruption in the system structure. Therefore, numbering is not consecutive. Regarding the notation format of the identification codes, both CoClass and Uniclass 2015 use a combination of alphanumeric characters. However, structural differences are observed between them because CoClass complies with IEC 81346-1:2022, which gives rules and guidance for the formulation of unambiguous reference designations for objects in any system. According to this international standard, it is recommended that letter and number codes be kept as short as possible for better readability; single-level reference designations with up to three letters and three numbers can be considered sufficiently short. Multi-level reference designations shall be constructed by prefix signs to concatenate multiple single-level designations [111]. In contrast, OmniClass® developers rejected alphanumeric identifiers and chose a purely numerical approach. The main reasons seemed to be the fact that (i) the use of the Latin alphabet would hinder the application in Asian countries, and (ii) there could be problems with visual identification between some characters (e.g. between O (upper case "o") and 0 (zero number)). Precisely to avoid this confusion, IEC 81346-2:2019 rules out the use of capital letters I and O from the Latin alphabet [112].

4.2. Application example for classifying a construction element

The main purpose of this subsection is to compare the coding structure of the three classification systems. In order to assess the adequacy of the three systems, an example of a request for the classification of the construction element "aluminium sliding exterior windows" is presented.

4.2.1. Example of coclass application

CoClass identifies 57 descriptions for "window"; 55 in the Object tables and 2 in the Properties table. Within the Object tables, the vast majority of results appear in the window types. As the goal is to show its use to the general public, the highest possible level of detail will be achieved with the free CoClass Bas license. Table 5 corresponds to the FS – Functional Systems table and classifies the space system which forms and separates space vertically as a "Wall system" (class B). The designation is the preferred term suggested in ISO 81346-12:2018 (Annex A.1).

In relation to the KS – Constructive systems table, the classification of the assembly system forming vertical separation as a "Wall construction" (subclass AD) is presented in Table 6. The terminology used is also consistent with ISO 81346-12:2018 (Annex A.2) recommendations.

In third and last place, Table 7 classifies the space access object for light entry only as a "Window" (class QQA), according to the KO – Components table. In this case, the terms used correspond to IEC 81346-2:2019 (Table 3).

Generally, the Constructive elements are defined from the concatenation of the codes of the three tables that form them: Functional systems (one letter), Constructive systems (two letters) and Components (three letters). Following this structuring criterion and the rules of IEC 81346-1:2022, the entire code sequence for a window on a façade could be: B.AD.QQA. Notice that in this example the

Table 5
Example of CoClass classification based on the Functional systems table (version 3.1.1, last updated November 2022).

Level	Coding structure	Title
–	1	Space systems
Class	B	Wall system

Table 6
Example of CoClass classification based on the Constructive systems table (version 3.1.1, last updated November 2022).

Level	Coding structure	Title
Class	A	Assembly system
Subclass	AD	Wall construction

Table 7
Example of CoClass classification based on the Components table (version 3.1.1, last updated November 2022).

Level	Coding structure	Title
Class level 1	Q	Controlling object
Class level 2	QQ	Space access object
Class level 3	QQA	Window

character "." (period/full stop) has been used as a prefix. In addition to class affiliation, other designators can be added with prefixes to identify the specific object, its type, function, location, and other relevant properties. Due to the limitations of the CoClass Bas license, it is not possible to state that the material (aluminium) and the opening type (sliding) can be specified in the class code. However, it would be feasible to indicate these characteristics by assigning an appropriate type ID. For example, if in a particular building project, aluminium sliding windows correspond to type 5, the code would be expanded in the following format: B.AD.QQA%F5 (F for Fönster meaning window in Swedish). Additionally, the Product ID can also be specified by adding the project numbering between class and type. For instance, if the aluminium sliding window was No. 30, it would be classified as follows: B.AD.QQA030%F5.

4.2.2. Example of uniclass 2015 application

If the same exercise is performed for Uniclass 2015, the search for a "window" gives a total of 75 results. Table 8 and Table 9 detail the hierarchical breakdown of the Systems and Products tables, respectively. Therefore, Uniclass 2015 offers the opportunity to identify "window" as a System belonging to wall and barrier systems, or as a Product included in the category of openings. This duality could confuse the professionals responsible for choosing the appropriate code. In relation to the level of detail required in the proposed example, although it is possible to indicate the type of material (aluminium), it is not feasible to specify the opening type (sliding).

As illustrated by the examples above, the coding structure of Uniclass 2015 consists of two letters to identify the table being used to classify the article (Ss_ for systems and Pr_ for products), and then broken down into groups of two-digit numbers to progressively increase the level of granularity.

Table 8
Example of Uniclass 2015 classification based on the Systems table (version 1.28, last updated October 2022).

Level	Coding structure	Title
Group	Ss_25	Wall and barrier systems
Subgroup	Ss_25_30	Door and window systems
Section	Ss_25_30_95	Window and window walling systems
Object	Ss_25_30_95_95	Window systems

Table 9
Example of Uniclass 2015 classification based on the Products table (version 1.28, last updated October 2022).

Level	Coding structure	Title
Group	Pr_30	Opening products
Subgroup	Pr_30_59	Openings and opening component products
Section	Pr_30_59_98	Window units
Object	Pr_30_59_98_02	Aluminium window units

4.2.3. Example of OmniClass® application

Finally, OmniClass® records the term "window" 215 times in four of its fifteen tables: Elements (Table 10), Work Results (Table 11), Products (Table 12) and Tools. The latter has been discarded from the study since it is limited to window-washing equipment. As explained in subsection 3.3, OmniClass® encourages early documentation in building projects to be organised according to Table 21 – Elements (based on UniFormat®). Later, when designers are thinking at a higher conceptual level, Table 22 – Work Results (based on MasterFormat®) is proposed to organise more complete specifications. It is noticeable that OmniClass® envisages the relationship between Table 21 and Table 22. In particular, it allows associating element 21-02 20 20 10 (Exterior Operating Windows) with work result 22-08 50 00 (Windows), located in the last additional column. To specify the material chosen in the proposed example, code 22-08 51 13 (Aluminium Windows) would be used instead. However, in order to describe the opening type, it would be necessary to use the identification of the product classes given in Table 23 – Products. Accordingly, the code 23-17 13 13 13 (Metal Horizontal Sliding Windows) would be the closest to the desired description, although the material would be defined in a broad way, without specifying the type of metal. The fact that such diverse codes can be assigned to identify the "aluminium sliding exterior windows" object could lead to collisions in the exchange of information throughout the life cycle.

Uniclass 2015 and OmniClass® list many types of windows in different tables. This has the advantage of offering a variety of window types to choose from. Unfortunately, it is impossible to cover all options, so there may not be a unique code for the type of window sought (as with the proposed example). In terms of consistency, it can be ambiguous and confusing that "window" can be classified with a different notation depending on whether it is considered a system, product, element or work result. CoClass has a very different encoding structure. In the main part of the code, the "window" component is explicitly and unequivocally classified by the QQA code. This classification scheme ensures a stable class code throughout the life cycle of the building, as the object is classified by its inherent function. Other characteristics of windows (such as material or opening type) could be added according to the rules for the construction of reference designations defined in the ISO/IEC 81346 series.

Table 10
Example of OmniClass® classification based on the Elements table (last updated May 2012).

Level	Coding structure	Title
Level 1	21-02 00 00	Shell
Level 2	21-02 20	Exterior Vertical Enclosures
Level 3	21-02 20 20	Exterior Windows
Level 4	21-02 20 20 10	Exterior Operating Windows

Table 11
Example of OmniClass® classification based on the Work Results table (last updated August 2013).

Level	Coding structure	Title
Level 1	22-08 00 00	Openings
Level 2	22-08 51 00	Metal Windows
Level 3	22-08 51 13	Aluminium Windows

Table 12
Example of OmniClass® classification based on the individual Table 23 Products (last updated May 2012).

Level	Coding structure	Title
Level 1	23-17 00 00	Openings, Passages, and Protection Products
Level 2	23-17 13 00	Windows
Level 3	23-17 13 13	Metal Windows
Level 4	23-17 13 13 13	Metal Horizontal Sliding Windows

5. Conclusions

This review provides comprehensive historical traceability of commonly used classification systems for the construction industry developed in Sweden, the UK and the USA/Canada. It also (i) outlines well-known national classifiers published in other regions, (ii) analyses the current state of the most widespread classification systems (CoClass, Uniclass 2015 and OmniClass®), and (iii) identifies recent initiatives to promote the adoption of a common classification system. The findings of this study will contribute to the benefits of designing standardised classification systems to describe the entire built environment. Based on the literature reviewed, the most important remarks, potential knowledge gaps and future research directions are summarised as follows.

- The emergence of the ISO 12006-2 standard, first published in 2001, was the first step toward the international standardisation of classification systems for the construction industry. For the first time, a framework was defined to facilitate harmonisation between systems and tables developed by the organisations concerned. The ISO/IEC 81346 series lays down rules for the construction of reference designations and classification schemes to provide stable class codes for objects.
- Significant differences have been detected between the structuring principles of CoClass and Uniclass 2015/OmniClass®. All three comply with ISO 12006-2:2015 and are based on long-standing national experiences. However, CoClass also complies with the ISO/IEC 81346 series, so its coding structure provides a consistent and unambiguous system for classifying building elements. Users can build the description of an object from the selection and assembly of appropriate facet codes, following a set of established rules. The Uniclass 2015 and OmniClass® tables also can be used independently or in combination. Nonetheless, rules to form unique codes for classifying object types are not explicitly specified.
- CCS (Denmark) and CCI (international approach) classification systems are very close to the CoClass structure, as they have been developed according to the guidelines of the same aforementioned international standards. Other countries such as Australia and Spain have developed their national classifiers, NATSPEC and GuBIMclass, respectively. Both can be considered more as a single classification table than a classification system (a set of tables representing different facets of the construction information).
- It has been noted that there is still no international consensus on using a common built environment classification system. The international non-profit organisation CCIC is actively working on the development of a unified and understandable language for building information management. The CCI system, first published in 2020, is intended to be used simultaneously by different countries in all technical fields and industries. As to its potential adoption, we believe that further work is needed to (i) complete the core tables (common to all participating countries), (ii) validate the suitability of the content of core tables in local applications, and (iii) develop national component tables.
- There is no established method for classifying objects in residential buildings in a consistent, unambiguous and standardised manner. Some classification systems duplicate classes in several tables, whereas others do not specify how to define some properties (e.g. material or type). Consequently, it has not always been possible to classify certain elements commonly found in residential buildings to the required level of accuracy. Further efforts are needed to implement the structuring principles and designation rules defined in the ISO/IEC 81346 series.
- While the use of classification systems throughout the asset life cycle is increasingly encouraged, they are primarily conceived to classify information acquired at the design and construction stages. However, this data will not always be available in existing buildings and should be collected on-site as part of technical inspections, with all the difficulties and constraints involved. It is therefore necessary to open up a new line of research to explore the challenges of identifying and classifying such information at the operation and maintenance stage. This particular approach opens up endless opportunities in existing building management (e.g. it could be implemented in a new functionality-oriented classification system).

CRediT authorship contribution statement

Veronica Royano: Conceptualization, Methodology, Investigation, Data curation, Writing - original draft, Writing - review & editing. Vicente Gibert: Resources. Project administration. Funding acquisition. Carles Serrat: Writing - review & editing. Supervision. Project administration. Jacek Rapinski: Writing - review & editing. Supervision. Funding acquisition.

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Data availability

No data was used for the research described in the article.

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