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Comparative Study of Construction Information Classification Systems: CCI versus Uniclass 2015

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Abstract: By classifying BIM data, the intention is to enable different construction actors to find the data they need using software and machines. The importance of classification is growing as building projects become more international, generating more data that rely on automated processes, which help in making better decisions and operating devices. Different classification systems have been developed around the world. Each national construction information classification system (NCICS) aims to classify information on the built environment and thus meet national needs and ensure compliance with the principles of regional and international building information systems. The research purpose of this paper is to present a comparative assessment of two construction information classification systems, CCI and Uniclass 2015. The following methods were used: the expert assessment of NCICS alternatives; the assessment of NCICS alternatives; and a strengths, weaknesses, opportunities, and threats (SWOT) analysis of NCICS alternatives. We concluded that in the initial phase of NCICS development, CCI ontologies should be adopted as a base consisting of construction entities, spaces, and elements, with the gradual addition of complexes of buildings and infrastructure, along with roles and phases of the building life cycle (BLC). An explanatory NCICS development note should be drawn outlining the principles of classification and identification; the ontological structure; development and updating possibilities; methods of integrating existing national and international classification systems; and methods of integrating data of construction products, time, cost, or other individual characteristics.

Keywords: building information modeling; CCI; Uniclass 2015; NCICS

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1. Introduction

At present, the construction sector faces the following potential problems:

- Insufficient compliance of public sector buildings with the needs of customers and public interests;
- Inaccurate identification of building construction goals and needs;
- Inadequate solution of building design analyses through a building's life cycle;
- Insufficient accuracy and quality of construction projects, and uncoordinated information exchange between participants and different information systems throughout a building's life cycle;
- Inefficient communication and cooperation between all participants involved in construction.

These problems are significant and affect the public construction sector in terms of planning, design, construction, operation, exploitation, and management. The rapid evolution and spread of information and communication technology (ICT) and new ways of working based on such technology have opened up new and innovative possibilities for solving these problems. One of the main solutions related to the application of ICT in the construction sector, which is rapidly being implemented globally, is the use of building information modeling (BIM) technology.

As a promising technology in the construction industry, BIM became widespread in the market in the early 2000s. BIM is more than a three-dimensional (3D) building tool; it can also be a multi-dimensional information model [1–6]. Key features of BIM include well-defined semantic and geometric data for each element and the ability to enable collaboration among stakeholders during the facility's life cycle [7]. According to the purpose of BIM, its application is observed throughout all stages of the asset life cycle. Architects, engineers, and builders use BIM throughout the design and construction stage, gaining the benefits of reduced errors, improved construction efficiency, communication and data exchange, and monitoring of costs and time [8–11]. Facility managers utilize BIM as a tool for maintenance planning and execution. As long as it contains relevant information, BIM can also be used during demolition.

There are cases when construction actors struggle because of poor data integration between BIM and existing information management systems. BIM adoption is relatively weak within operational and maintenance (O & M) organizations (estate and infrastructure management) that could gain maximum value from using BIM [12].

Both BIM and the digital twin (DT) concept are applicable to increase efficiency in the architecture, engineering, construction, and operation (AECO) industry throughout building life cycle stages. There is still a need for research to clarify the relationship between digital twins and other digital technologies and their key implementation challenges [13,14].

Classifying BIM data in an agreed way (such as a common BIM language) enables different construction actors to find the data they need using software and machines. Building projects are becoming more international, generating more data and relying on automated processes to help make better decisions and operate devices. That is why the importance of classification is increasing [15]. Various classification systems have been developed around the world for different BIM data and users: Uniclass 2015, a unified classification system that covers all construction sectors in the UK and internationally [16]; OmniClass, a classification system for the construction industry, mostly in North America [17], which inherited MasterFormat®, a standard for organizing specifications and other information for building projects in the United States and Canada [18]; UniFormat™, a standard for classifying building specifications and estimating and analyzing cost, in the US and Canada [19]; CoClass, a classification system for the built environment, in Sweden [20]; CCS, a classification system for the built environment, in Denmark [21]; TALO, a classification system in Finland [22]; NS 3451 and TFM, a classification system in Norway [23]; CCI, which covers the entire construction sector, based on a series of international standards [24]; Industry Foundation Classes (IFC), the buildingSMART data model standard [25]; the buildingSMART data Dictionary (bSDD), a library of objects and their attributes [26]; and ETIM, the international standard for uniform classification of technical products [27].

A study was conducted on the proposal for a national standard in Sweden [28]. The authors defined the following requirements for the proposed standard: it should connect to BIM and national registers, be based on a national classification system for the urban environment, and support the development of 3D city models. The authors suggested that the national building standard follow international standards and include classification systems.

The hierarchy of classification systems splits the object into discrete categories in each space and hierarchically disintegrates it into its main components [29]. Each class code is used for component instance detection, and is a simplified representation that often carries the most important information about an instance [30]. According to the standardized classification, models can be defined that are relatively semantically unambiguous for both knowledgeable computers and people [31]. Owners need the same classification system to define maintenance tasks [32]. As noted in [33], the hierarchical classification has limited performance. Facility management (FM) requires information to be collected from various sources and integrated for a coherent understanding of the construction of the building or infrastructure. A significant data source is occupant-generated complaints and subsequent requests for specific actions. When data are transferred from one information system to another, the goal is to achieve a data transformation process that can later be used to provide automated transformation [34]. A comprehensive classification system can be used to discover the topic and some metadata from actual project documents [35]. In one study [36], a classification method was proposed for design changes and "three categories of data changes (property data, appearance data, and relationship data) and three levels of design changes (instance level, type level, and model level)" were developed. Another study [37] investigated how "to employ deep learning, a subset of machine learning, to automate the classification of subtypes of BIM elements" using the IFC schema. However, such classes are not assigned by the major model view definitions, and thus "they need to be specified manually, exposing data exchanges to potential human and interpretation errors" [37]. Positive results support "the feasibility of using support vector machines (SVMs) to verify the mappings of the BIM element to the IFC class", as well as allow for automated subtype classification within individual IFC classes [36].

National Construction Information Classification System. Currently, the digitalization process in the public construction sector is addressed at the government level, with recommended or obligatory BIM models presented together with construction proposals. However, there is insufficient professional and scientific information and comparative analyses of different classification systems.

The aim of each national construction information classification system (NCICS) is to classify the information on the built environment (buildings, engineering facilities, their territories, etc.) and thus meet national needs (national classification systems, value assessment, and cost estimation databases) and ensure compliance with the principles of regional and international building information systems and standards. The purpose of making comparisons among NCICSs is to identify the strengths and weaknesses of each alternative system; therefore, the research reflects recommendations for countries or clients in order to choose the appropriate approach.

In this paper, we raised the following questions to decide which construction information classification systems would be relevant for comparison:

- From what aspect should the information of construction objects be classified?
- How is the classification applied?
- What is the basic principle for grouping this information?

The classification systems were divided into groups to answer the questions according to the proposed criteria (Table 1).

Table 1. Assignment of comparable construction information of global classification systems when evaluating classification results.

	Group 1	Group 2
Main facet of classification system	Functional	Structural (related to local and/or functional facets)
Classification system point of view	Functional	Compositional
Basic principle of information grouping	Faceted	Hierarchical

Although composed according to different logic, these classification systems (Table 1) reflect the same results of classifying construction information according to ISO 12006-2.

The CCI [24] classification system, which takes the functional classification perspective, is significant as a regional system. It can adequately represent this classification point of view (Table 1, group 1) as it has the same basis as CoClass [20] and CCS [21].

Uniclass 2015 [16], which takes a composite classification point of view (Table 1, group 2), is global and is one of the most comprehensive parts of the classification systems proposed according to ISO 12006-2. Therefore, Uniclass 2015 can well reflect the compositional-hierarchical principle. Uniclass 2015 and CCI were chosen due to their popularity and applicability to national legal environment issues; Uniclass 2015 is similar to Omniclass and provides more detailed classes (Table 1, group 2), and CCI is similar to CoClass and CCS and provides more generic, function-based classes (Table 1, group 1).

For that reason, in this paper we analyze and compare two alternative construction information classification systems:

- Construction classification international (CCI) [24] is a mixture of international ISO/IEC 81346 standards and the Cuneco (Denmark) and CoClass (Sweden) classification systems developed based on these standards. CCI is based on a regional initiative between Northern and Eastern European countries (Czech Republic, Denmark, Estonia, Poland, Slovakia, and Sweden) to standardize information on the built environment. Currently, CCI consists of general classes (according to the available scheme based on ISO 12006-2), such as construction complexes, entities, spaces, and elements, classified into functional systems, technical systems, and components. This classification system clearly describes the definitions of classes, code attribution rules, and a functional approach to classified objects. Currently, the CCI core consists of more than 1.3 thousand classes, which govern buildings and their complexes, premises, all types of systems (load-bearing, covering, protecting, supplying, and distributing), separate components of building structures, and engineering systems.
- Uniclass 2015 [16] is a construction information classification system developed by a private funding organization, National Building Specification (NBS), supported in the UK and recognized internationally. Currently, Uniclass 2015 consists of the following general classes (according to an available scheme based on ISO 12006-2): construction complexes, entities, spaces, elements, construction information, roles, construction and project management processes, construction products, and construction aids. The classification system has a deeply rooted hierarchy in which the properties of objects become parts of classes. Currently, Uniclass 2015 contains more than 14,000 classes that classify buildings and their complexes, premises, functional systems, and building life cycle (BLC) processes, the roles of construction agents, CAD attributes, specific elements of building structures, and engineering systems with the respective properties.

Countries planning to implement BIM as an obligatory tool will have to prepare uniform rules and normative documents. They will have to select national classification systems of construction information for proposals of public procurement documents when applying the BIM methodology. However, there is a research gap in the professional and scientific information with regard to comparative analyses of different classification systems.

This paper aims to present a comparative assessment of two construction information classification systems, CCI and Uniclass 2015, using the following methods:

- Formation of four evaluation models and their criteria;
- Expert evaluation of NCICS alternatives using the ranking technique;
- Assessment of NCICS alternatives;
- SWOT analysis of NCICS alternatives.

2. Methods

The following methods were used:

(1) The authors chose an expert survey approach to determine the values of NCICS alternative criteria or the physical meaning of the significance of qualitative criteria, which shows how often it is more or less useful to an object in a complex assessment of alternatives rather than another option [38].

First, a group of 11 experts was formed, who had to meet the following requirements:

- At least 5 years of experience in applying BIM methodology in the civil engineering field;
- Certified as a civil engineer (e.g., technical supervisor, project manager, BIM coordinator, designer, or similar) or researcher in civil engineering;
- Knowledge and application of Lithuanian and foreign construction technical and legal documents;

- Experience in using the construction information classification system, with preference for experts who have used CCI and Uniclass 2015;
- Due to the specifics of the construction information classification system, no lower than English level C1.

The work of the selected experts took place in two stages. In the first phase, the experts were asked to analyze and compare the CCI and Uniclass 2015 systems, highlighting four relevant assessment models for an emerging national construction information classification system. In the second stage, the experts assessed the NCICS alternatives using the ranking technique. Due to the pandemic situation, a combination of questionnaire and telephone conversations (only for clarification of the assessment methodology) was chosen. We created an electronic form to compare the NCICS alternatives in terms of the four assessment models (and a questionnaire with instructions and template tables was created for the expert survey, presented below). Non-anonymous questionnaires were sent to the experts in electronic format; subsequently, the methodology for filling in the questionnaire was repeatedly explained over the phone.

According to the list of criteria provided by the experts, the compliance of the two systems with the requirements was assessed by filling out the survey, in which the experts analyzed and rated the alternatives as more important (highest rating = 4) or less important (lowest rating = 1). To analyze and compare the construction information classification systems, we examined them and distinguished between national criteria; flexibility, development, and clustering; development, adoption/adaptation of a web-based information system; and compliance with ISO 12006-2:2015.

(2) Strengths, weaknesses, opportunities, and threats (SWOT) analysis was used to asses CCI and Uniclass 2015. Weaknesses (unfavorable internal factors that are disadvantageous compared to other options), opportunities (favorable external factors that may help to reach the goal), and threats (unfavorable external factors that may hinder reaching the goal) were analyzed based on NCICS goals. The SWOT method identifies favorable and unfavorable internal and external factors in terms of strengths (resource-related favorable internal factors that are potentially advantageous compared to other alternatives). SWOT analysis shows how to best use available strengths and opportunities and helps to find ways to neutralize negative factors by using positive internal and external factors or even turning weaknesses into strengths and threats into opportunities.

3. Results and Discussion

3.1. NCICS Alternatives Assessment Modelling

To analyze and compare the alternative construction information classification systems, we distinguished between four assessment models developed by the experts (Figure 1):

- National criteria;
- Flexibility, development, and clustering;
- Development, adoption/adaptation of a web-based information system;
- Compliance with ISO 12006-2:2015.

First, four evaluation models were formulated based on which peer review could be carried out. Following the requirements described in Section 2, a group of 11 experts was formed, who established evaluation criteria for each evaluation model separately. We then systematized the obtained results (Tables 2–5), and created a questionnaire survey, which was used for further stages of the research.

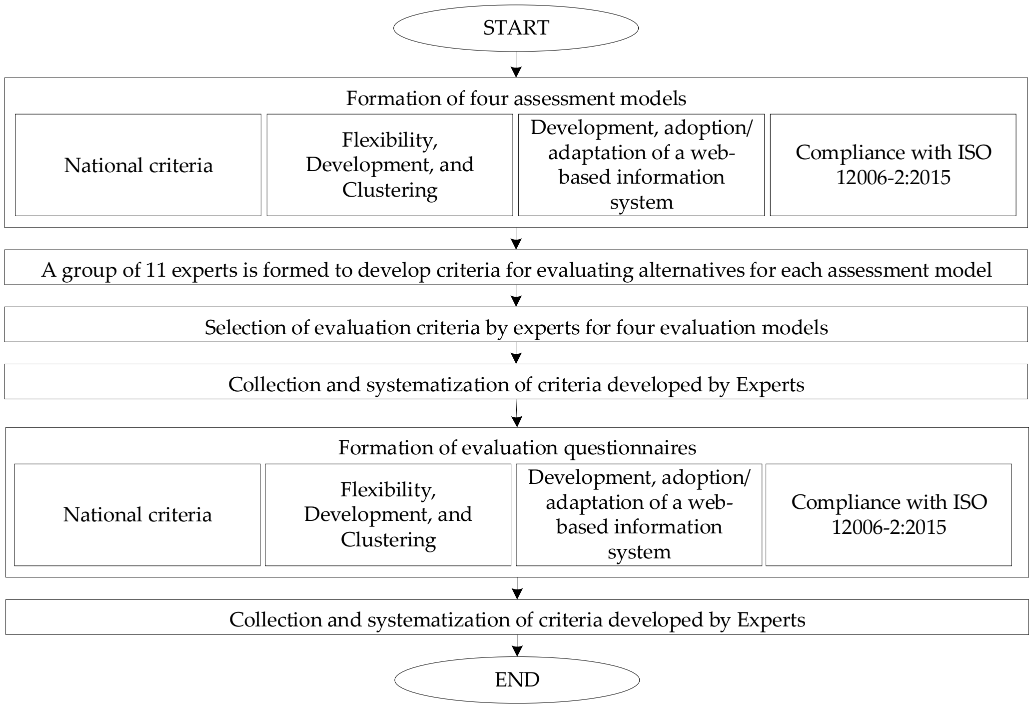

Figure 1. Schematic of development of four evaluation models (drawn by authors).

Table 2. NCICS alternative assessment model in terms of national criteria.

National Assessment Criteria for NCICS Alternatives	CCI	Uniclass 2015
Possibility of linking to national GKTR [39], SEDR [40], and SSBKDS [41] classification systems.	Only indirect linking is possible * (ISO/IEC 81346 series standards define mechanism of linking external information to properties section).	Linking is not possible.
Possibility of linking to classification systems governed by Building Technical Regulation 1.01.03:2017, Classification of buildings.	Only marginal direct linking is possible ** because CCI defines classification of buildings.	Only marginal direct linking is possible.
Possibility of linking to national construction cost estimation database.	Only indirect linking is possible (ISO/IEC 81346 series standards define mechanism of linking external information to properties section).	Linking is not possible because fixed prices and their specifications are defined.
Possibility of linking to roles, agents, and types of building construction governed by Law on Construction of the Republic of Lithuania.	Full integration of nationally regulated roles, actors, and construction types is possible as CCI does not define them.	Linking is not possible because roles are defined.
Possibility of linking to Classification of Territories.	Construction complexes are defined; marginal link possible.	Construction complexes are defined; marginal link possible.
Regional distribution in terms of building design and construction/production services.	Classification systems developed according to ISO/IEC 81346 standards have been widely used in Denmark, Sweden, Estonia, Russia, and Kazakhstan.	Uniclass 2015 is widespread in UK, Canada, and Australia.

* Indirect linking is understood as the absence of unambiguous correspondence of one class to another; therefore, linking is only possible by attributing one class to the properties or attributes of another class (if the methodology provides so). ** Direct linking is understood as an unambiguous correspondence of one class to another, 1:1.

Table 3. NCICS alternatives assessment model in terms of flexibility, development, and clustering criteria.

Flexibility, Development, and Clustering Assessment Criteria of NCICS Alternatives	CCI	Uniclass 2015
Stability of identification code of classification system in BLC.	Abstract functional classes or technical systems provide stability for the identification code (a fixed part in the BLC stages).	Abstract functional classes provide stability for the identification code (a fixed part in the BLC stages).
Identifier of generic class.	Yes, available. Generic class identifier is marked by < > or (), e.g., <L> refers to construction elements, <C> refers to construction complexes.	Yes, available. Generic class is marked by two letters, e.g., Pr refers to construction products, En refers to construction entities.
Ontology extension and updating possibilities.	Easier to extend and update due to grouping of classes based on letters, i.e., 24 capital letters can be chosen to define particular classes (I and O should not be used if confused with 1 (one) and 0 (zero)). ISO/IEC 81346 series of standards was particularly directed at industrial facilities; as a result, a narrow classification zone was assigned to structural components (e.g., vast majority of structural components are classified using the letter U, which designates holding objects).	More difficult to extend and update due to many already determined classes (more than 14,000). More difficult to extend and update due to deep-rooted hierarchical structure (four hierarchical levels in product group). More complicated to change detailed and profound Uniclass 2015 classification due to already determined intervention in the existing structure.
Application at international level (internationalization).	Based on international standards and widely used in Northern and Eastern European countries (Denmark, Sweden, Russia, Kazakhstan, and Estonia). Adoption in Czech Republic, Belgium, and other countries planned.	Has good links with US classification system Omniclass. Used in the UK, Canada, Australia, and other countries.
Grouping principles (faceted, hierarchical). Note: Faceted classification system is made of two or more separate tables that allow entities to be classified from different perspectives, e.g., an object can be assigned to an item class, an actor's role, a process, a piece of equipment, etc.	Faceted classification system is based on hierarchies (according to ISO 12006-2) such as construction entities, spaces, and elements, which are classified into functional systems, technical systems, and components.	Faceted classification system is based on hierarchies (according to ISO 12006-2) such as construction complexes, entities, spaces, elements, building information, roles, construction and project management processes, construction products, and construction aids.
Possibility for customization.	ISO/IEC 81346 provides possibility of integrating user-defined features, data from national classification systems, or other types of information into reference designation system. This mechanism makes classification system more flexible, but also more cluttered. Standard recommends that content of individual properties be already established by national legislation.	No rules defined for information customization and integration.

Table 4. NCICS alternative assessment model in terms of online IS.

Criteria for Assessment of NCICS Information System	CCI	Uniclass 2015
Access to existing information systems (ISs) and their application programming interfaces (APIs).	Prototype of CCI information system is based on CCS IS, available online at https://ccs.molio.dk/ (accessed on 20 January 2022). CoClass system, which is based on CCI and ISO/IEC 81346 standards, is available online at https://coclass.byggtjanst.se/ (accessed on 20 January 2022). These information systems have application programming interfaces (APIs).	Existing IS of Uniclass 2015 classification system has an API and is available online at https://www.thenbs.com/our-tools/uniclass-2015 (accessed on 20 January 2022).
Support, development, and intellectual property rights for existing IS.	CCI international initiative was developed and is supported by a coalition between Denmark, Estonia, and the Czech Republic, among other countries. CoClass was developed and is supported at national level by Swedish Transport Administration, Swedish Construction Agency, and Swedish BIM Alliance. CCS was developed on the initiative of Molio, an association of the Danish construction sector, and supported by the public sector.	Uniclass 2015 was developed and is supported by National Building Specification (NBS), founded by Royal Institute of British Architects. This organization brings together many players from the construction industry and public and private entities (builders, manufacturers, designers, asset managers) in the United Kingdom.
Functionality of user interface.	CCS (CCI) IS user interface (https://ccs.molio.dk/ (accessed on 20 January 2022)) is in line with modern web design: has detailed search and filtering tool, possibility to annotate classes, and ability to export classes to xls and pdf formats. Additional advantages include partial linking of classes to IFC scheme classes and display of all class information in the same window. Disadvantages: browsing and search speeds are often inferior compared to other information classification system ISs; structure of classification tree does not fit into specified window width, which makes reading and browsing awkward. Several bugs were detected during IS testing. CoClass IS user interface (https://coclass.byggtjanst.se/ (accessed on 20 January 2022)) follows modern web design, is intuitive, has a search tool, allows annotation of classes, and has a clear tree structure and illustrations of certain classes. Disadvantages: browsing and searching speeds are lower compared to Uniclass 2015 IS.	Uniclass 2015 IS user interface (https://www.thenbs.com/our-tools/uniclass-2015 (accessed on 20 January 2022)) is consistent with modern web design, is intuitive, has a search function, is simple, and has sufficient search speed. Disadvantages: class lists are broken down into groups of 10 items, which is not convenient for viewing a large list on one screen. In many cases, user has to navigate through individual pages to see entire search result or group of classes. Does not have a class annotation feature, nor are classes explained or illustrated.
Accessibility and subscription.	CCI ontologies are publicly available and have national use and deployment rights granted. CCI is free of charge. Basic CoClass IS package is publicly available in Swedish and English. Full studio version comes with extended classes and class types. CCS IS is free of charge and publicly available in Danish and English.	Uniclass 2015 IS basic package is free of charge and publicly available in English. Provides access to all ontologies of classification system and downloadable tables in xls format. Subscription-based (paid) version of NBS Chorus provides detailed technical specifications based on Uniclass 2015 classes that can be used to define required BIM data, perform cost estimations, and carry out other tasks.

Table 5. Compliance with ISO 12006-2:2015 assessment criteria for NCICS alternatives.

Compliance with ISO 12006-2:2015 Assessment Criteria for NCICS Alternatives	CCI	Uniclass 2015
A.2: Construction information	-	FI: Form of information (105 classes)
A.3: Construction products	-	Pr: Products (7471 classes)
A.4: Roles, agents	-	Ro: Roles (226 classes)
A.5: Construction aids	-	-
A.6: Management activities	-	PM: Project management (460 classes)
A.7: Construction processes	-	Ac: Activities (926 classes)
A.8: Construction complexes	Complexes (78 classes)	Co: Complexes (390 classes)
A.9: Construction entities (entities)	Entities (175 classes)	En: Entities (479 classes)
A.10: Built spaces (premises)	Spaces (144 classes)	SL: Spaces/locations (860 classes)
A.11: Construction elements	Functional systems (17 classes) Technical systems (102 classes) Components (799 classes)	EF: Elements/functions (90 classes) Ss: Systems (2248 classes)
A.12: Work results	-	-
A.13: Properties	-	Zz: Properties of CAD drawings (140 classes)

Note: dash (-) indicates that NCICS alternative does not define ontologies for corresponding generic class.

The model for assessing the NCICS alternatives in terms of national criteria was based on the possibility of integrating existing national classification systems that describe the built environment in Lithuania and the related data stored in information systems. Another important group of modelling criteria was focused on adapting the classification system ontologies to the Lithuanian language and terminology. Tables 2–5 present the analysis results based on the process shown in Figure 1.

The NCICS alternatives assessment model focuses on classification structure, reference designation, upgradeability, and personalization regarding flexibility, development, and clustering criteria. Table 3 presents the analysis in detail.

The NCICS information system (IS) is understood as the combination of a processing system and the resources used for information processing, generation (creation), and dissemination (sending and receiving).

Considering the 24/7 accessibility requirement and the availability of the NCICS application programming interface, it is important to assess these in terms of the existing and/or future online information system. Information systems of both alternatives could be adopted to some extent, but in any case, adapting to the national environment would be inevitable. Table 4 presents the analysis in detail.

ISO 12006-2 describes the general structure of information on construction objects. The environment was divided into construction resources, processes, and results. Construction results were broken down into 12 top-level classes, which are generally adopted as the basis for many international building information classification systems (Omniclass, Uniclass 2015, CCS, CoClass, etc.). The model to assess compliance with ISO 12006-2 principles is shown in Table 5.

3.2. Expert Assessment of NCICS Alternatives Using the Ranking Technique

Prioritization of the NCICS alternatives was carried out according to the national flexibility, development, and clustering information system and ISO 12006-2:2015 compliance evaluation criteria using the expert approach. The experts analyzed the criteria of NCICS alternatives in the same way they did with the groups of alternatives, ranking them as very important (highest rank of 4 to 12, depending on the number of criteria) or less important (lowest rank of 1). The NCICS alternative groups were ranked according to general criteria, which the experts evaluated as very significant (highest rank of 4) or less significant (lowest rank of 1).

A schematic presentation of the prioritization of the criteria groups of NCICS alternatives, the ranking, and the criteria values is shown in Figure 2.

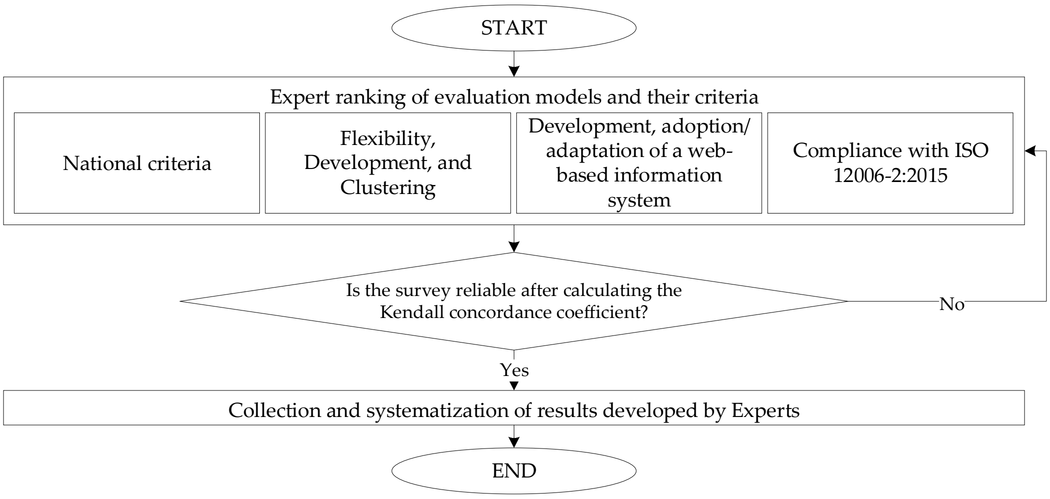

Figure 2. Schematic representation of expert ranking of evaluation models and their criteria (drawn by authors).

The overall ranking of the criterion groups in relation to each other (Table 6) was determined before the ranking of each group individually. Then, the criteria of each group of NCICS alternatives were ranked (Tables 7–11).

Table 6. Ranking of criteria groups and values of Kendall's concordance coefficient.

	Criteria Groups	Concordance Coefficient (*W*) Value	Results Evaluation
Group rank	Overall ranking of criteria groups for NCICS alternatives	0.920661	Reliable
1	National	0.932883	Reliable
2	Flexibility, development, and clustering	0.824321	Reliable
3	Information system	0.907438	Reliable
4	Compliance with ISO 12006-2:2015	0.957926	Reliable

Table 7. National evaluation criteria for NCICS alternatives, their ranking in importance order, and compliance with alternatives.

Group Rank	National Evaluation Criteria for NCICS Alternatives	CCI	Uniclass 2015
1	Possibility of linking to national Technical Regulation of Geodesy and Cartography (GKTR) and municipal spatial dataset (SEDR) classification systems	1	0
2	Clarity of terms (classes) and their description	2	0
3	Possibility of linking to classification systems governed by Building Technical Regulation 1.01.03:2017, Classification of buildings	1	1
4	Possibility of linking to national construction cost estimation database	1	0
5	Possibility of linking to building life cycle (BLC) model	2	1
6	Regional distribution in terms of building design and construction/production services	1	1
7	Possibility of linking to roles, agents, and types of building construction governed by applicable national legislation	2	0
8	Possibility of linking to national classification systems of territories (land-use types and subtypes)	2	1
9	Adaptation of adopted terminology to national setting	2	1
10	Languages of classification systems	1	1
	Aggregate criteria fulfilment value	15	6

Table 8. Flexibility, development, and clustering evaluation criteria of NCICS alternatives, their ranking in order of importance, and compliance with alternatives.

Group Rank	Flexibility, Development, and Clustering Evaluation Criteria of NCICS Alternatives	CCI	Uniclass 2015
1	Customization possibility	1	0
2	Ontology extension and updating possibility	2	1
3	Stability of classification system code mark in BLC	2	2
4	Identifier marked with highest code	2	2
5	Application at international level (internationalization)	1	1
6	Grouping principles (faceted, hierarchical)	1	1
	Aggregate criteria fulfilment value	9	7

Table 9. Information system evaluation criteria of NCICS alternatives, their ranking in order of importance, and compliance with alternatives.

Group Rank	Information System Evaluation Criteria of NCICS Alternatives	CCI	Uniclass 2015
1	Access to existing information systems (IS) and their application programming interfaces (APIs)	2	1
2	Functionality of user interface	2	1
3	Support, development, and intellectual property rights for existing IS	2	2
4	Accessibility and subscription	2	2
	Aggregate criteria fulfilment value	8	6

Table 10. Compliance with ISO 12006-2:2015 evaluation criteria for NCICS alternatives, their ranking in order of importance, and compliance with alternatives.

Group Rank	Compliance with ISO 12006-2:2015 Evaluation Criteria for NCICS Alternatives	CCI	Uniclass 2015
1	A.11: Construction elements	3	2
2	A.9: Construction entities	1	1
3	A.10: Built spaces	1	1
4	A.8: Construction complexes	1	1
5	A.7: Construction processes	0	1
6	A.13: Properties	0	1
7	A.4: Roles, agents	0	1
8	A.3: Construction products	0	1
9	A.2: Construction information	0	1
10	A.5: Construction aids	0	0
11	A.12: Work results	0	0
12	A.6: Management activities	0	1
	Aggregate criteria fulfilment value	6	11

Table 11. Aggregate scores of NCICS evaluation criteria by importance and their compliance with alternatives (in points).

Order of Importance	Ranking of Evaluation Criteria for NCICS Alternatives	CCI	Uniclass 2015
1	National	15	6
2	Flexibility, development, and clustering	9	7
3	Information system	8	6
4	Compliance with the ISO 12006-2:2015	6	11
	Aggregate criteria fulfilment value	38	30

The ranking of criteria is considered to be reliable if there is sufficient consistency between the experts' opinions. Kendall's (1970) concordance coefficient W was calculated to check the reliability of the survey [42]. The application of this coefficient to calculations related to the consistency of expert opinions has been described [43–46]. The value of concordance coefficient W is calculated according to the formula:

$$W = \frac{12S}{r^2(n^3 - n)} \quad (1)$$

where S is the sum of the squares of the deviations of the sum of the ranks of the performance criteria from the overall mean of the ranks, r is the number of experts, and n is the number of criteria.

When there are small differences between expert assessments, the concordance coefficient is close to 1, and when the assessments differ significantly, the concordance coefficient is close to 0.

The values of Kendall's concordance coefficient obtained for the ranking of criteria groups and individual groups of NCICS alternatives are presented in Table 6.

The priority order of the NCICS alternatives was calculated using the expert approach (Figure 3). The experts ranked the national evaluation criteria of NCICS alternatives as the most important and compliance with ISO 12006-2:2015 as the least important. The ranking of the five groups revealed the most significant groups of alternatives and the individual alternative assessment criteria.

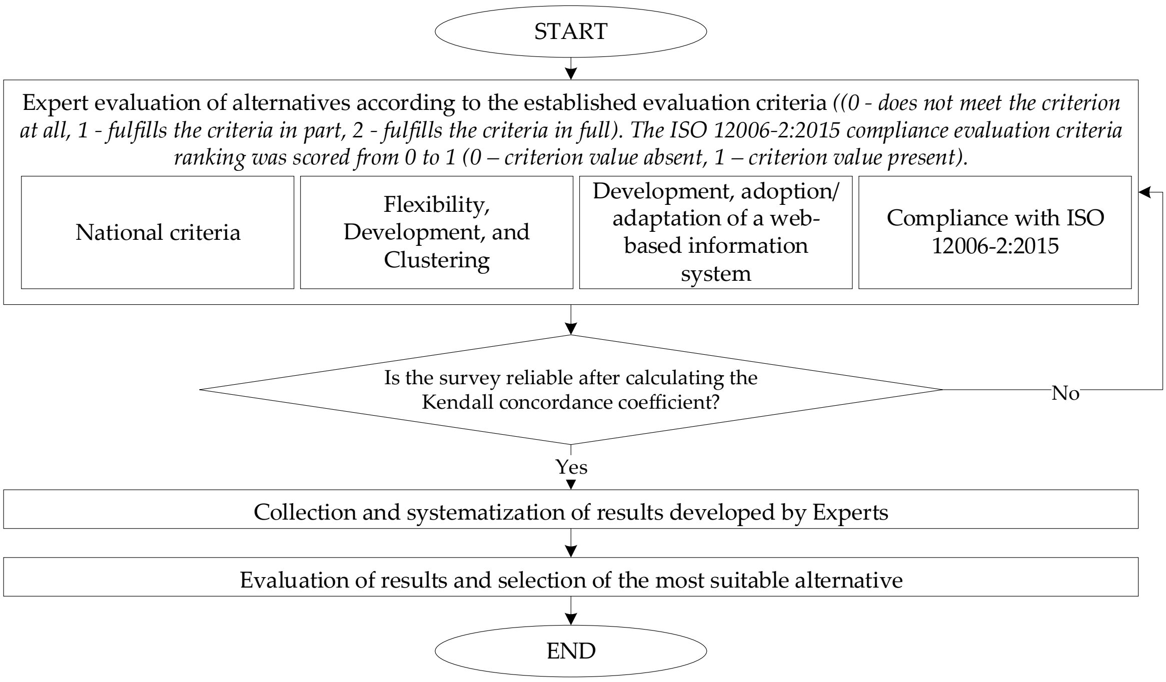

Figure 3. Schematic representation of expert evaluation of alternatives according to established evaluation criteria (drawn by authors).

The criteria of each group of NCICS alternatives were ranked in the second phase. The order of NCICS alternatives for each group was developed according to the ranks obtained. The compatibility of the expert survey was calculated for each group.

The priority order of the criteria for NCICS alternatives according to the ranking is presented in the first column of Tables 7–11.

The evaluation of whether the CCI and Uniclass 2015 alternatives met the criteria of each group was performed in the third phase of the assessment.

The criteria to be met were scored with points from 0 to 2 (0, does not meet the criterion at all; 1, partly meets the criteria; 2, fully meets the criteria). The ISO 12006-2:2015 compliance evaluation criterion was scored from 0 to 1 (0, criterion value absent; 1, criterion value present).

After summarizing the expert evaluation results, we noticed that the 11 experts evaluated all the alternatives equally. The calculated values of Kendall's concordance coefficient were equal to 1. This paper presents a non-summed assessment of one expert; to obtain a summed score of all experts, each number should be multiplied by 11. This was not performed in the study because there was no difference in determining the most suitable alternative.

The results obtained are presented in Tables 7–11, with the aggregate criteria fulfilment values in the bottom rows.

Table 11 presents the aggregate results of expert evaluations. The table shows that the CCI alternative received the highest score according to the compliance criteria in the top three groups of alternatives and the fifth group. In the fourth and lowest group of criteria, Uniclass 2015 scored the best; however, in the experts' opinion, CCI complied more with the most significant criteria. The aggregate criterion scores were 38 for CCI and 30 for Uniclass 2015, which also met the lower rank criteria.

The NCICS evaluation model in terms of flexibility, development, and grouping criteria reveals that both alternatives have a multi-hierarchical grouping principle that allows objects to be classified from different perspectives (e.g., the same object can be assigned by type, construction agent role, process, construction aids, etc.). Multi-hierarchical classifiers are flexible (easier to edit and update), provide more information (reference designation) about the object being classified, and create more uncertainty about which multi-hierarchies to apply.

Given the significant fragmentation of information on the built environment, there is no doubt about the need to adapt individual properties to the alternative of group 1 (Table 1). Unique properties, in this case, are understood as additional information that is not included in the regulated classes. CCI group 1 (Table 1) was primarily focused on industrial production, so the basic ontologies are enriched with classes of engineering production systems. In this case, classes that describe the structures of the buildings will also have to be developed.

The advantage of Uniclass 2015 group 2 (Table 1) is its large number of classes, which ensures broad and deep classification of the built environment. However, several major shortcomings call Uniclass 2015 into question as a possible alternative to NCICS: many classes do not have relevant national descriptions, which is likely to lead to classification errors, translation gaps, and difficulties in practicability.

The human-readable coding structure features both NCICS alternatives, but Uniclass 2015 does not set rules for the identification system. CCI can fit two or more multi-hierarchies (multi-level reference designations) into a single line of code, which provides more options from a software standpoint.

CCI group 1 (Table 1) establishes coding principles and rules (using appropriate prefixes) that can evaluate a classified object from different aspects: function, location, type, structure, or other. For example, when classifying in terms of location, the position of the object on another object (handle on a door or reinforcement in a masonry wall) or the GIS location of the object can be indicated. The functional aspect is useful in functional schemes of engineering systems. The structural aspect is focused on the components of the object. Uniclass 2015 group 2 (Table 1) does not identify the mentioned or similar methodology.

4. SWOT Analysis of NCICS Alternatives

As mentioned in the Methods section, NCICS alternatives were evaluated using SWOT analysis. The SWOT analysis of CCI as a potential NCICS alternative is presented in Table 12.

Table 12. SWOT analysis of CCI as an NCICS alternative.

STRENGTHS	WEAKNESSES
• Conforms to ISO 12006-2, which ensures compliance of classification system with international principles of classifying information about construction works • Based on international standard ISO/IEC 81346, which forms basis of CCS (Denmark) and CoClass (Sweden) classification systems, with cases of application in Estonia, Russia, Czech Republic, and Kazakhstan • Compatible in terms of design and export of construction services due to increased implementation in Eastern and Southern European countries • ISO/IEC 81346 family of standards provides a methodology (specific rules) for linking individual attributes, national classification systems, or other additional external information • Provides reference designation system (RDS), which identifies objects within structures and ensures possibility to structure objects according to different aspects (function, structure, location, type, other); has a functional approach to classes that ensures certain stability of reference designations in classification system throughout BLC • Functional classes are useful for describing functional patterns (movement, flow, change), or non-fixed objects, especially useful to convey meaning of engineering systems • Has highly flexible coding syntax; possible to place multiple hierarchies (several parts of code) into one line of code according to different aspects • Coding principles make it possible to indicate position of classified object within another object (location aspect)	• Standardized number of classes does not accurately describe objects of built environment, thus additional ontologies have to be developed or mapped with additional sources • ISO/IEC 81346 series is centered on engineering systems of buildings, so classes of structures and some parts of civil objects require further detailed breakdown and development
OPPORTUNITIES	**THREATS**
• Possible to link existing national classification systems related to built environment (e.g., construction agents, BLC phases), individual or only project-relevant properties (e.g., materiality, coordinates, addresses, etc.), or other types of information by using ISO/IEC 81346 attach properties rule	• Part of general classes according to ISO 12006-2 (roles, construction information, processes, etc.) is not established, which may cause deviations from international principles of construction classification while integrating national classification systems

The SWOT analysis of Uniclass 2015 as a potential NCICS alternative is presented in Table 13.

To summarize the SWOT analysis of NCICS alternatives, the main advantages of CCI over Uniclass 2015 are its ability to link national construction classification systems or other types of information, the application of RDS with the ability to identify objects within the structure, and clear definitions of classes. The main advantage of Uniclass 2015 over CCI is its many classes with detailed characteristics about objects (classifying more than 14,000 objects of the built environment).

The analysis of weaknesses and opportunities of CCI and Uniclass 2015 revealed the main disadvantages of these alternatives. The nature of CCI originating in the manufacturing industry and electrical engineering field is considered a drawback. Uniclass 2015 has no object identification and codification rules and many classes that do not have descriptions, leading to ambiguous classification. The threats it poses include large-scale intervention in the established national framework of construction legislation and an expected need for significant resources to implement the changes.

Table 13. SWOT analysis of Uniclass 2015 as NCICS alternative.

STRENGTHS	WEAKNESSES
• In full accordance with ISO 12006-2, which ensures compliance of classification system with international principles of classifying information about built environment • Broad and profound classification system that contains more than 14,000 classes of built environment • Ensures seamless links with Omniclass classification system (USA) • Well established internationally; popular in the UK, Canada, and Australia • Has plug-ins for popular BIM software packages	• Descriptions of classes are absent, causing ambiguity due to unclear terminology • Many classes (>14,000) and deep hierarchical structure of 5 breakdown levels make it difficult to apply classification system quickly in practice • Many classes (>14,000) creates ambiguity, which can lead to misclassification of objects • Some features (e.g., materiality) are already built into construction products, promoting an intensive increase in number of classes (currently 7471 classes); no clear strategy on limits • Object identification system and its link to classification system are unclear (not defined)
OPPORTUNITIES	**THREATS**
• Building information classification system is an essential part of BIM methodology, thus Uniclass 2015 would allow smoother adoption of mature British BIM methodology	• Complete adoption of Uniclass 2015 would create wide-ranging intervention in established national system of construction legislation and require additional resources to implement changes in legal framework and train public and private sectors • Package of paid services (NBS Chorus) may prevent full application of classification system for small market participants

5. Conclusions

1. Regarding existing national classification systems and the pronounced fragmentation of information on the built environment, there is no doubt about the need to customize individual characteristics by applying a rule of properties based on the IEC/ISO 81346 series standards. In this context, individual characteristics are understood as additional information that is not included in the CCI classes. All existing national classification systems and their references, codes, terminology, etc., can be linked to the NCICS.
2. The most commonly cited advantage of Uniclass 2015 is its large number of classes (more than 14,000), with it providing a broad, detailed, and profound classification of the built environment. However, several major drawbacks cast doubt on the use of Uniclass 2015 as a possible NCICS alternative: the lack of descriptions for many classes can lead to classification errors, ambiguity, and difficult applicability. Full adoption of Uniclass 2015 would create a wide-ranging intervention in the existing national system of construction legislation, requiring additional resources to implement the changes in the legal framework to train the public and private sectors.
3. The expert evaluation of compliance by CCI and Uniclass 2015 with the criteria of each group showed that the most important group, national evaluation criteria of NCICS alternatives, scored 15 points in the CCI and 6 in the Uniclass 2015 classification. The evaluation of the second group, flexibility, development, and clustering evaluation criteria of NCICS alternatives, showed that CCI received 9 points and Uniclass 2015 7 points. The situation is similar for the information system evaluation criteria, where CCI scored 8 points and Uniclass 2015 scored 6. The compliance with ISO 12006-2: 2015 evaluation criteria was assessed by the experts as the least significant, with CCI scoring 6 points and Uniclass 2015 11 points, but the total number of points for all criteria groups, 38 for CCI and 30 for Uniclass 2015, showed that the more important criteria were more in line with CCI.
4. The NCICS alternatives under consideration comply with ISO 12006-2:2015, Building construction—Organization of information about construction works, Part 2: Frame-

work for classification, which establishes general principles for the classification of construction information and ensures links between classes at the top of the hierarchy with other international classification systems. However, the current version of Uniclass 2015 covers more of the general classes of ISO 12006-2:2015 than CCI (10 vs. 4).

5. Due to the export of design and construction services and the prevailing initiatives in the European Union and other countries, ISO/IEC-81346-based classification systems are widespread; they are widely used in Sweden and Denmark, and cases of their application are known in Estonia, Finland, Russia, the Czech Republic, and Kazakhstan. Uniclass 2015 is most widespread in the UK. It is also used in Canada, Australia, and sporadically in other countries.
6. Both NCICS alternatives have functional class groups, which ensure specific coding stability in the classification system throughout the BLC phases (planning, design, construction, and use).

The following principles should be considered in subsequent stages of NCICS development:

- In the initial phase, the CCI ontologies should be adopted as a base consisting of construction entities, spaces, and elements, with the gradual addition of complexes with buildings and infrastructure, roles, and BLC phases.
- An explanatory NCICS development note should be drawn outlining the principles of classification and identification; the structure of the ontologies; development and updating possibilities; methods of integrating existing national and international systems; and methods of integrating data of construction products, including time, costs, and other individual characteristics.
- An NCICS application guide should be developed with practical examples (classification, identification, coding) and recommendations that consider different parts of the project, BLC phases, software, and exchange of data (coded labels) using open standards.

This research was carried out based on construction legislation in the Republic of Lithuania. This could be perceived as a limitation. However, the conclusions and evaluation principles could be useful and could be applied to evaluate and implement construction information classification systems in other European countries or internationally. Future research directions could involve comparing other classification systems or providing additional criteria for comparison.

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