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Tactile maps of historical gardens: method of content selection

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Abstract

Historical gardens are a significant part of the cultural heritage. Exploration of such gardens is an important element of education. A particular challenge is to increase the accessibility of these facilities for the people with visual impairments (PVI). Among the aids enabling PVI visiting the gardens are tactile maps. The currently used tactile maps focus mainly on orientation and mobility. They do not allow exploration of gardens as a spatial composition, taking into account their cultural values. Therefore, the aim of our study was to develop the rules for content selection of tactile maps presenting those features of gardens that decide about their value, and to formalize these rules using the Unified Modeling Language (UML). In this research we analyzed features of 15 gardens in the five garden design styles: Baroque, Renaissance, English, Romantic, and Japanese. In result, we have proposed the way of mapping of the five garden design styles in a form useful for PVI. We have defined the procedure of content selection, as well as the catalogues of elements to be mapped at different levels of details, distinguishing repetitive and unique elements of each style. Finally, we have defined the easy-to-use list of content elements of tactile maps in the five design styles. Our solutions are described in a formalized way that allows their unambiguous understanding and universal application. The proposed solutions contribute to increasing the accessibility of gardens to PVI and allow them to learn about the values of cultural heritage of such places.

Keywords Cultural heritage, Tactile maps, Accessibility, People with visual impairments, Standardization, UML

Introduction

In recent years we can observe a trend of increasing inclusiveness of people with special needs. Institutions managing cultural and natural heritage make efforts to ensure that facilities such as museums can be visited by everyone. Historical gardens, as immovable monuments, are of particular importance for the recognition and significance of the place, country and state (e.g. [1, 2]). They are living cultural documents shaped by the influence of social and political conditions, cultural relations and trends of their era [3]. But in addition to aesthetic values, they often became the center of research, education, and places for recreation and educational activities of nature and history observation, as well as diverse collections of plants and architectural monuments [4]. In order to popularize these places and make it easier to visit them, or to reconstruct their history and development, various forms of visualization and applications are created (e.g. [5, 6]). Unfortunately, not all potential users can easily visit the gardens and explore their values, although in many countries such access should be legally assured to everyone, e.g. the Americans with Disability Act [7].

Visiting the gardens by people with special needs is a big challenge. Numerous facilities and improvements are being introduced for people with movement and hearing impairments, or the autism spectrum disorder [8–10]. However, these facilities are not enough for people with visual impairments (PVI)—they usually require assistance from friends, family or employees of the cultural institution they are visiting [11, 12].

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Besides, by not seeing the historic gardens, they have no opportunity to directly learn what is valuable in them; not to mention that in many cultural institutions, PVI are forbidden to touch the exhibits [13].

The value of each garden lies in its unique composition covering a large area and containing an arrangement of specific elements, such as different types of flora, small garden architecture, water elements and alleys. They are juxtaposed with each other in such a way that they create a harmonious whole. Exploration of such compositions as a whole is difficult even for people with good eyesight, but is much more complex for PVI.

Therefore, to facilitate exploration of a garden we could reduce its size. A natural "tool" to present a reduced image of a fragment of the Earth is a map. The biggest advantage of a map is that it can present the real relationships between real-world objects, even those covering large areas, in a convenient way [14]. Tactile maps can thus be used to increase the accessibility of historical gardens for PVI. Although the sight provides the fullest sensory experience, it is possible to represent spatial phenomena in the non-visual domain and create tactile maps that can be perceived using the senses of touch and hearing [15].

Maps for PVI can take different forms, e.g.: relief models, auditory maps, audio-tactile information systems or even vibrotactile maps. Most commonly, tactile maps contain both tactile and highly contrasting graphic content, usually supported by audio content, that can be perceived by PVI. However, the finger's ability to distinguish between individual objects is about 10 times worse than that of the eye [16, 17]. Therefore, in order for a map to be read by touch, it must be properly adapted and significantly simplified, i.e. spatially generalized [18, 19]. Besides, tactile maps should be safe and convenient to use, as well as—in case of maps to be used in public spaces: durable.

Tactile maps can be produced using different techniques on a variety of substrates, which greatly impacts the quality of the final product [20]. For example, using swell paper results in cheap and foldable but at the same time less durable tactile maps; thermoforming is cost-effective only in case of large-scale production but the resulting maps are, inter alia, water-resistant and comfortable to use; 3D printing allows almost unlimited freedom in tactile signs design at a relatively low cost but requires the use of rather complex hardware [21]. Selected production technique greatly affects the symbology of the target tactile map, as well as its redaction and generalization approaches. For this reason, the media selection should always be consulted with the target user group, prior to the actual design phase.

Another factor that has to be considered are the tactile map sheet's dimensions. Different sizes and proportions of the map sheets are used, depending on the content they present. Usually they are similar to A4 [22] or A3 format [23–25] so that the seated user can cover the map with their arms and freely touch its entire surface [26]. All this means that there may be few features of content on a single tactile map sheet, with strongly simplified shapes.

Therefore, the key challenge when developing tactile maps is the optimization of their content, i.e. the selection of features on the map so that the user with visual impairment can read them freely, and at the same time, to provide them with as much information as possible. This is a complicated and time-consuming task, and the results obtained are largely subjective, depending on the skills and experience of a tactile cartographer. In addition, tactile maps production is expensive, which additionally affects the low availability of such materials [27].

Similar problems apply to tactile maps of historical gardens. Based on the results of the questionnaire that we have distributed on social media, 88% of PVI indicated gardens as the tourist attraction type they tend to visit [28].

Tactile maps are sometimes offered as aids while visiting gardens, e.g. at the Museum of King III's Palace in Wilanów [29]. However, usually their only purpose is to orient in space or delineate a route between two points—and not getting to know the garden as a unique historic spatial composition. Therefore, they usually depict only paths and the most important features for orientation in space and safe, independent movement, and are not necessarily related to the values of the garden itself. This is due to the fact that there are no standardized solutions of presenting the cultural values of gardens on tactile maps. No defined rules exist for the selection and presentation of the tactile map content that determine the value of the garden as a cultural heritage site.

Solving the above problems, related to the design of tactile maps, may increase the chances of PVI getting to know historical gardens. This is important because the map is present in the everyday life of every sighted person and is one of the basic sources of knowledge about the world. The map serves not only as a tool to get to know a fragment of the Earth and relationships between objects in space. In addition, by using the map, many thought processes can be carried out, allowing to see the specificity of forms and peculiarities of the spatial arrangement of features, compare the size and regularity of the distribution of phenomena and reveal spatial connections.

The role of maps in the lives of PVI is even greater than in the case of sighted people. The main way PVI obtain information is through language—speech.

However, not all images built by PVI on the basis of oral transmission are correct. Besides, combining different sensory experiences, e.g. sound and touch, facilitates cognition and contributes to better memorization. Therefore, it is important to enable PVI to know an object, phenomenon or space through various sensory impressions.

Unfortunately, not everything can be perceived by touch in its natural dimensions, e.g. large or distant objects. Hence the great importance of all kinds of drawings, plans, maps, etc. Using them gives PVI a chance to reduce the negative effects of providing information only by means of language. Ideas and concepts created on the basis of information obtained through various channels, including information obtained independently, better correspond with the surrounding reality, which is an important condition for self-development [30]. Therefore, the role of maps, which are the main source of information about the environment and the basis for getting to know the space, is so important.

In the case of gardens, the map plays a special role, because it allows to present the garden features arrangement on a small area as works of art, designed in a thoughtful way and representing the characteristics of eras and styles. Compared to other forms of presentation tailored for PVI (e.g. audio descriptions), tactile maps allow a visually impaired user to explore the historic space at their own pace, by reading it repeatedly, returning to particular elements and performing new cognitive operations in an individually chosen order.

Thus, the main assumptions of our study was that tactile maps should present the characteristic features of historical gardens that form a composition in the original garden design style so that PVI could experience the cultural values of such heritage sites. Features could be of many kinds and can be differently composed with each other, depending on the historical period in which the garden was designed and what garden design style dominated its establishment. Therefore, the content selection of tactile maps of historic gardens is subject to additional difficulty related to the selection and generalization of the features determining their unique value.

Taking the above into consideration, the aim of the research was to develop a methodology for selecting and generalizing the content of historical garden maps in various garden design styles, taking into account the design requirements of maps for PVI. The specific objective is also to formalize the proposed principles in the form of Unified Modeling Language (UML) diagrams as a means of digital documentation of cultural heritage. In view of the above, two research questions were asked:

A) How to map historical gardens to reflect the uniqueness and values of their compositions using tactile maps?
B) Which components of the methodical selection of the content of tactile maps of gardens could be described in a formalized way?

The starting point for the developed methodology was the analysis of the characteristics of the gardens in five design styles: Baroque, Renaissance, English, Romantic, and Japanese. In section "Materials and methods", we describe the research methodology and present the case study used for its validation. In section Results, we present the results, mostly in the form of UML diagrams. Chapter Discussion discusses the results and the advantages and disadvantages of the presented methodology.

Materials and methods

Research methodology

Research assumptions

The main assumption in our research was that historical gardens were created in different periods and thus, designed in different styles. Each style has its own features, reflecting characteristics of a given period and the prevailing trends in garden design. These features are related to the presence of specific objects in the garden, as well as to their distribution and mutual relations. The garden composition forms a harmonious whole and determines its uniqueness along with the style in which the garden composition was designed.

For many years of their existence, historical garden compositions have often undergone changes, reconstructions and devastations. Therefore, the original style often remains unpreserved in the current garden's form, is preserved only rudimentarily or the garden is a mixture of several styles. In this research, it was assumed that the proposed way of selecting the content of maps applies to gardens in which the design style features have been preserved to such an extent that it is possible to clearly determine the original design style.

The second assumption is related to the perceptual capabilities of PVI. In addition to the limitations in tactile mapping mentioned in the Introduction, the number of cartographic tactile signs should not be greater than the number of elements distinguishable by PVI. On a single tactile map sheet no more than 6–7 types of point, 3–4 line and 3–6 area signs should be used [31–34]. The total number of unique symbols should be limited to 10–15 [31]. This limitation makes it extremely important to use the unified character convention, that is, to represent the same type of feature in the same way on different maps, which increases the efficiency of perception and facilitates their understanding. Therefore, the selection of content ranges for maps of historical gardens will be carried out simultaneously for several garden design styles in order to identify those elements of content that repeat across different styles and those that are unique for a given style.

Methods used

Currently, some cartographers argue that the process of cartographic media use is dynamic and reciprocal between user and cartographer, therefore the ontological basis of cartography should be reconsidered [35]. Although it is fairly easy to find arguments to confirm this thesis in classical cartography, in tactile cartography, which is not so well-developed, the biggest challenge is to improve access to maps for PVI. In our opinion, research on tactile mapping should be still concentrated on how to design maps and on development of rules that simplify and speed-up tactile mapping, rather than by critically examining the assumptions underpinning the notion of a map as a mean of knowing of the world.

Taking the above into consideration, the method of content selection of garden tactile maps was based on the classical method of map development, using cartographic methods of learning about reality [36]. This method involves selecting the parts of reality, and then presenting them as a reduced image of the Earth's surface or its part in a small area of a map. The map is read by the recipient to obtain information from it that is then interpreted in the form of knowledge about the mapped fragment of reality. The cartographer's task in this process is to elaborate a map that will provide the user with the closest possible picture of reality. It is therefore necessary to select the information that is relevant for a specific map and then generalize them in a way that reflects the characteristics of the mapped area in the most objective way. This choice is influenced by many issues that determine the form of the map, which are slightly different for tactile and traditional maps because both, the scope of the content and the way it is presented, must be adapted to the perceptual capabilities of the recipient. In the case of tactile maps there are more limitations determining the final form of a map as it was previously stated. Additionally, tactile maps are being read fragment by fragment out of which the mental image of the whole is constructed in the reader's mind [23]. On the other hand, while using sight, one can usually capture the whole mapped phenomenon at once. This results in more time required for tactile perception of maps. Differences between factors determining the design of tactile (our approach) and traditional maps (previous approach) of gardens are presented in Table 1.

To adapt tactile maps limitations into cartographic methods of learning about gardens' reality, a thought experiment was conducted. It was based on the features of gardens in various design styles. One of the empirical research methods was applied—the method of analysis and synthesis [37]. In this method, general truths are extracted (synthesis stage) on the basis of the elementary theorems obtained earlier (analysis stage). This process allows for discovering the connections between the individual elements of the whole.

In our research, we obtained elementary theorems by analyzing all features of gardens in various styles and their meanings in defining each garden style as well as objects representing them. We also analyzed the diversification of the spatial arrangement of objects determining each garden style and composition. At the analysis stage, comparative methods were used to compare features of gardens in different styles to determine similar or unique features for each of the garden design styles. On the basis of the gardens' elementary properties, their synthesis was

Table 1 Comparison of our and previous approach in designing maps of gardens

Issues determining the form of a map	Previous (traditional maps)	Our (tactile maps)
Mapping method	Classical method of map development	
Perception resolution	Eyesight: 0.15–0.3 mm	Touch: 2.4–3.0 mm
Map reading	From general to specific	Linear cognition
Primary factors influencing the map content	Topic Properties of the mapped area Scale Purpose	Readability Strong generalization Sheet size Limited number of cartographic signs
Secondary factors influencing the map content	The nature of the source materials Presentation methods	Topic Properties of the mapped area
Way of content selection	Separately for each map, in each scale	Jointly for a set of maps in different garden design styles and at different level of details
Cartographic signs design	Different on each garden map	Repeatable on different garden maps

performed taking into account the limitations of tactile mapping. The synthesis aimed to define the following issues:

- the areas to be mapped at various levels of detail in each garden style in order to reflect particular style's characteristics together with rules for their selection;
- the stages of the procedure of content selection;
- the catalogues of all garden styles features/objects (along with their repeatability/uniqueness definition) for each map levels, their classifications depending on features importance in particular's style definition;
- the ready-to-use tactile map content scopes for each garden design style at every level of map detail.

Brainstorming and idea reduction methods were used at the synthesis stage to support unambiguous definition of details of the above issues.

Formal description in UML

In our methodology we combine knowledge on cartography, tactile perception and the art of garden design. Precise and understandable explanation of this interdisciplinary research in an unambiguous way for all interested parties is difficult using the natural language. Therefore, they were described using UML (Unified Modelling Language) to ensure proper understanding and develop tactile maps in accordance with the proposed methodological solutions, i.e. to facilitate the implementation of the solutions proposed in our research [27].

UML is a language used to model the problem domain, i.e. to formally describe a fragment of the existing reality. Makes it possible to describe assumptions and solutions, as well as to document the existing or final state in a graphical way in the form of diagrams. These diagrams enable the formal description and modelling of structures or processes in a way that is understandable both for the technical team implementing solutions in e.g. GIS software, as well as for the stakeholders, e.g. users of the designed solution. UML diagrams are divided into those that describe the structure, such as a class or component diagrams, and diagrams that model the behaviour—such as a use case, activity or sequence diagrams.

In the formal description of the method of the tactile map content selection in UML [38], the following diagrams were used. The issues related to the determination of the mapping areas are described using the analytical class diagram (section "Mapped areas"). Activity diagrams were used to present the principles of developing the content of tactile maps (section "The procedure of content selection"). A package and class diagrams were used to represent the classification of map content (section "The catalogues of features at each level of detail"). For the purpose of including geometry in the definition of individual feature types in the UML class diagrams (Figs. 10, 11, 12, 13, 14) the ISO 19107 standard was used [39]. The rules for creating and describing classifiers in the class diagram were formulated in accordance with the ISO 19103 standard [40].

Case study

The proposed methodology was tested on the example of 15 historical gardens in five different design styles: Baroque, Renaissance, English, Romantic and Japanese. These design styles have many things in common but they differ greatly.

The basis of the Renaissance garden design style (Fig. 1) is the main axis of symmetry and numerous smaller lines crossing it, dividing the garden into geometric quarters with formed trees, shrubs and usually a fountain placed in its central point. The quarters are separated by pergolas, treillages, benches etc. The structure of the garden is often terraced. Such terraces are connected by stairs and ramps. Many places are hidden from the sight of walkers ("giardino secreto"). There are sculptures, stone benches and little walls in the garden. Many of the above elements are also used in Baroque garden design style (Fig. 2). Baroque gardens are representative gardens, showing the wealth of the owner. In this style, the palace and the garden form a common architectural layout, creating a symmetrical and geometrically perfect space with alleys intersecting usually at right angles. Garden parterres are characteristic features of this style, with compositions made of flowers that look like patterned carpets. Trees are formed into geometrical shapes, and grouped in bosquets that are used as a contrast for short garden parterres. The flora and garden architecture are used to divide gardens into numerous rooms for various purposes, including: offices, theaters, and corridors. The garden's architecture also includes pergolas, stone vases, sculptures of mythical and fairy-tale characters, parade stairs and much more. Water is usually present in the form of long geometric water reservoirs.

As opposed to the geometric assumptions of the Renaissance and Baroque styles, landscape gardens were developed. Landscape gardens are generally much more extensive, with less variety of objects and fewer architectural elements. An example of a landscape gardens are English gardens (Fig. 3) characterized by a large area with groups of natural trees or shrubs and minimal presence of small garden architecture. Very characteristic is a single, sprawling tree growing on a vast lawn or among a

Fig. 1 Renaissance garden—Wawel Royal Castle in Kraków ([41] and own sources)

Fig. 2 Baroque Garden at King Jan III Palace Museum in Wilanów (Warsaw) ([41] and own sources)

flower meadow—a solitaire. The landscape gardens also include Romantic gardens with naturalistic plant forms (Fig. 4). These gardens are asymmetrical, with winding paths and seemingly spontaneous distributed sculptures and small architecture objects and are usually separated from palaces. There are many sentimental objects, such as commemorative boulders, caves, benches, artificial ruins, as well as those referring to antiquity (temples), the Orient (columns, sarcophagi, buildings) or Chinese architecture.

Japanese gardens (Fig. 5) are characterized by harmony, simplicity, asymmetry and elegance. Japanese gardens are a miniature landscape, where each element has a symbolic meaning. Such gardens consist of two main parts: a water reservoir and a hill. On the banks of the water reservoir, stones are arranged in an orderly manner, whereas the streams are enriched with cascades, waterfalls and footbridges. The paths are natural, covered with sand or gravel. There are rich flora with fanciful shapes (e.g. bonsai). The garden architecture includes stone lanterns and

Fig. 3 English garden in Krasiczyn ([41] and own sources)

Fig. 4 Romantic Park in Arkadia ([41] and own sources)

columns, garden pavilions, as well as tea houses and Tori gates.

For each style three representative examples of Polish gardens were selected. For the Renaissance design styles the examples are as follows: Gardens of Książ Castle, and the Royal Castle in Warsaw, as well as the Wawel Royal Castle in Kraków. Baroque Garden at King Jan III Palace Museum in Wilanów, Baroque Garden in Nieborów and Park at Zamoyski Museum in Kozłówka are the representatives of the Baroque design style. For the English landscape design style we have selected the City Park in Skierniewice, Szczytnicki Park in Wrocław and the Castle and Park Complex in Krasiczyn. For the Romantic design style the representatives are the Romantic Parks in Arkadia, Bukowiec and Puławy. Finally, we have selected the Japanese Garden in Wrocław, Jarków and Siruwia in the town of Przesieka as the representatives of the last analysed style—Japanese. Location of the gardens in Poland together with the styles identification are presented in Fig. 6.

In order to learn about the features of the gardens and the selection and classification of the content of the tactile maps, a reconnaissance was conducted for selected gardens, as well as an analysis of the source cartographic studies and the descriptions of the gardens.

Fig. 5 Japanese Garden in Wrocław ([41] and own sources)

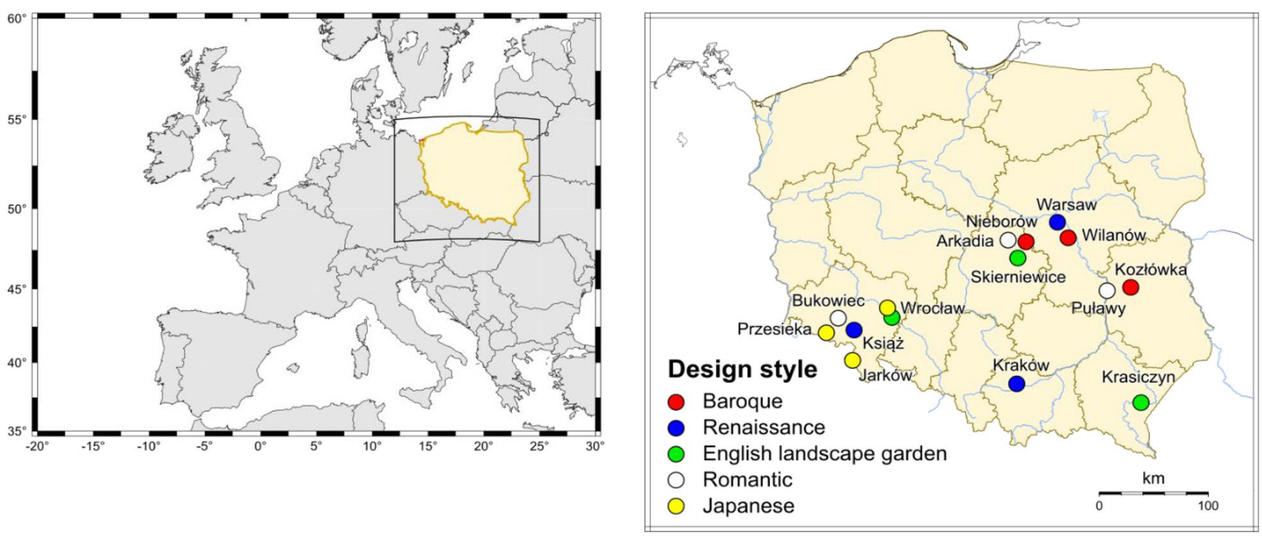

Fig. 6 A case study—gardens location (own work)

Results

Mapped areas

Based on the gardens' features and their spatial distribution analysis, we found that each garden composition should be mapped on different levels of detail because it is impossible to show all features of garden styles on a single tactile map sheet due to the previously discussed need for a strong content generalization (simplification). Therefore, we have defined basic rules for selecting areas to be mapped, together with the levels of detail on which they should be presented.

When mapping gardens at different levels of detail, we have considered two types of generalization—qualitative and quantitative [14]. Quantitative generalization includes omitting less important elements of the map, e.g. simplifying the course of streams (form generalization) or omitting less important elements of garden architecture (content generalization). Qualitative generalization includes generalizing the concepts presented on a map by, for example, representing parterres and lawns in one common "low vegetation" category (grouping).

In our methodology, we have defined a set of rules to parametrize the map development process. The first rule for selecting areas to be mapped refers to the first level of detail (hereinafter referred to as “I level”) and it says that the entire composition of the garden should be mapped on a single map sheet no larger than the A3 size. This map will present the garden in a small scale, with a significant degree of content simplification, using both qualitative and quantitative generalization [14].

The next rule says that the representative fragment of the garden, covering the place of accumulation of features characteristic for a given design style, should be mapped with more details on an additional map sheet (max. A3 size). It results in the second level of detail map (II level). For each garden composition, at least one II level map should be developed. Such a map will contain more detailed style features compared to the I level map—both in terms of quality and quantity.

In case of gardens with many features characteristic for a particular style, the map on the third level of detail will be also developed (III level). On such a map, the most unique part of a garden in a given style with features that do not appear in other garden design styles should be presented. These characteristic parts of the gardens will be presented in great detail, using mainly quantitative generalization.

We present the above concept in the UML analysis diagram (Fig. 7). A “stick man” icon represents actors, which could be both personal and impersonal phenomena or concepts. The boundary classes (“rules for I level map”, “rules for II level map”, “rules for III level map”) adhere to artifacts that are used by or associated with the selected actors. A control class (“define map area”) represents a process that could be started when one of

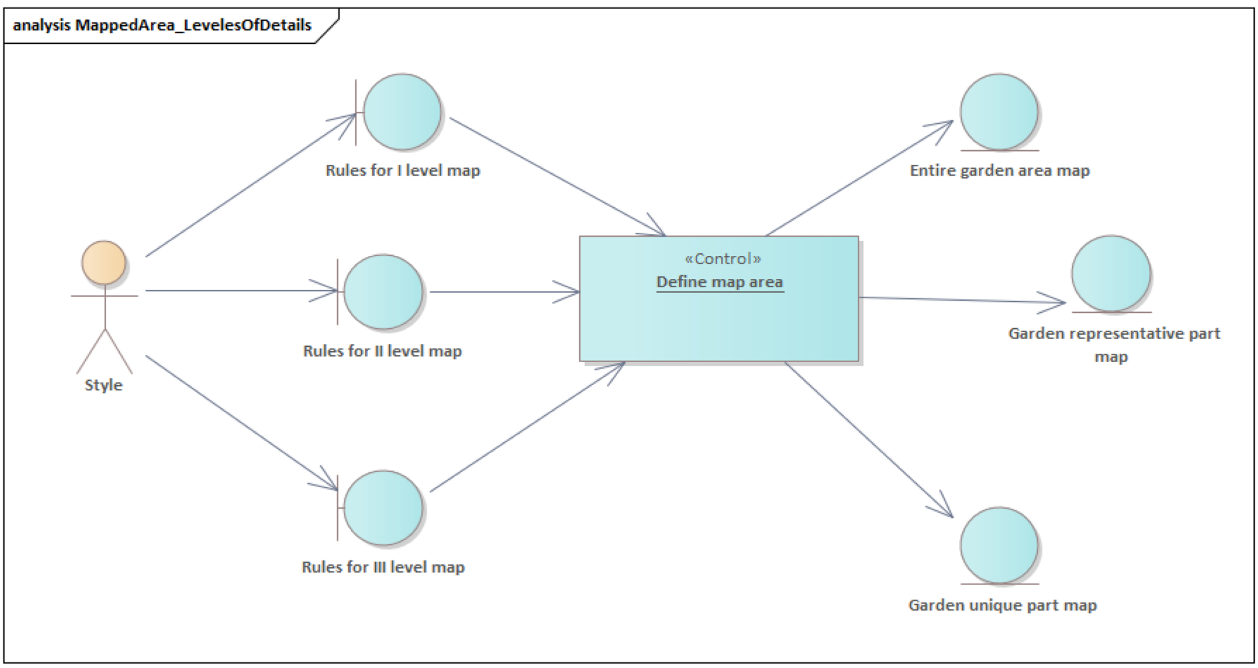

Fig. 7 Areas mapped at different levels of detail (UML analysis diagram)

Table 2 Specific areas mapped in various styles

	Style name	I. Level Entire garden area	II. Level Garden representative part	III. Level Garden unique part
1	Baroque	The whole garden composition	Terrace or fragment on one side of the main axis of symmetry	Garden parterre
2	Renaissance	The whole garden composition	Terrace	Viridarium
3	English	The whole garden composition	Fragment with small architecture, water, bridge	–
4	Romantic	The whole garden composition	Fragment with buildings	–
5	Japanese	The whole garden composition	Waterfall area	Dry garden (kare-sansui)

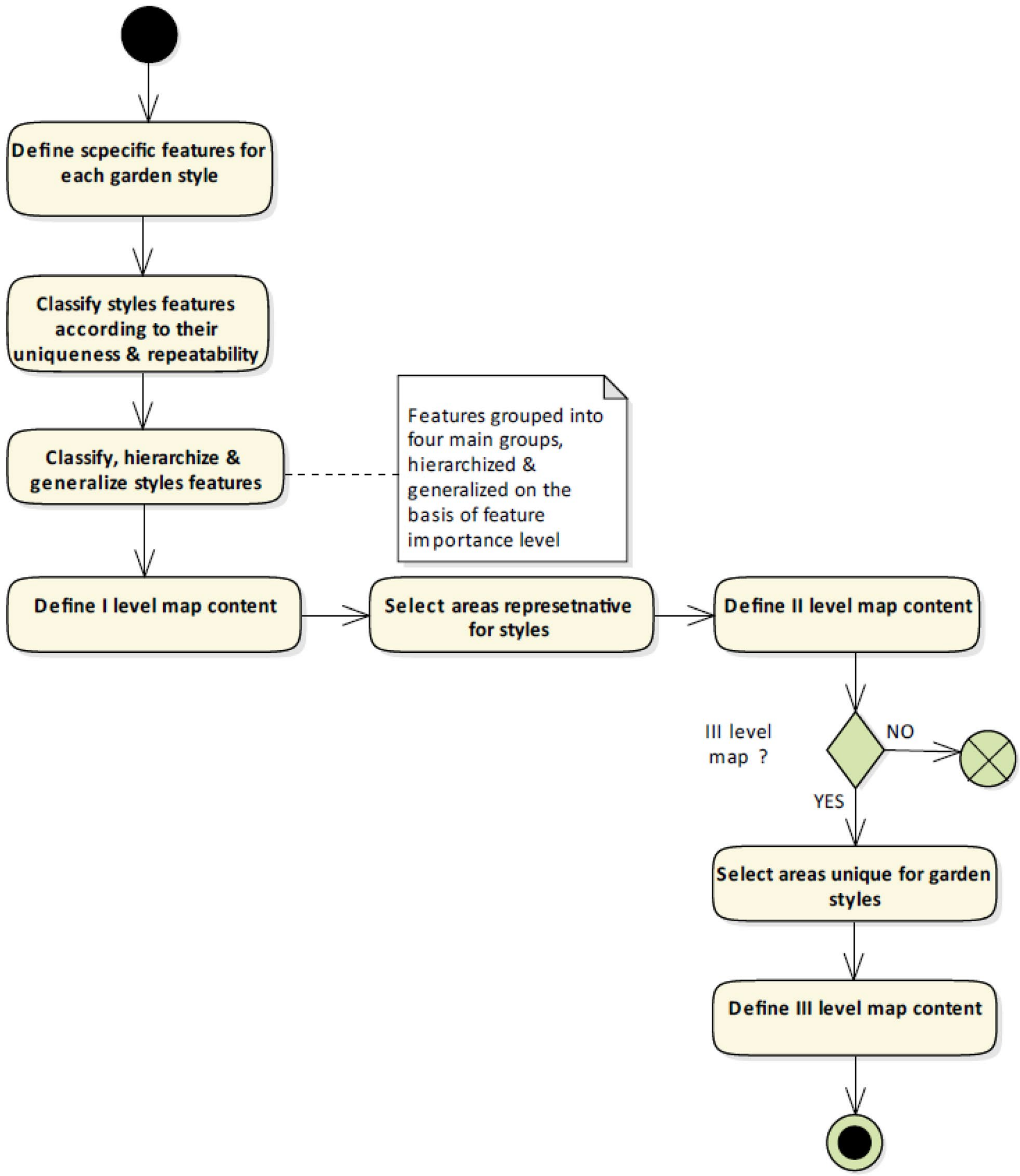

Fig. 8 Procedure of the tactile maps content selection of historical gardens (UML activity diagram)

the boundary classes is indicated. The process results in different forms of data storage or visualization that are represented as the entity classes ("entire garden area map", "garden representative part map", "garden unique part map").

According to the above rules we have selected areas for mapping in each analyzed style at various levels of detail (Table 2). Each garden should have a map of the whole composition at I level and a more detailed map at II level, covering different areas in different styles. Only Baroque, Renaissance and Japanese gardens have a map at III level because they are characterized by a greater number and concentration of style features. For more extensive gardens, but relatively homogeneous with less diversified features such as Romantic and English, only two levels of map detail are sufficient.

The procedure of content selection

We divided the procedure of content selection into a few stages. To present the procedure we used the UML activity diagram (Fig. 8). Stages are represented by "activity" notation elements and the stages order. Relationships between selected actions are presented by the use of control flow and decision elements. We added additional comment to the selected stage using UML note (i.e. "Classify, hierarchize & generalize styles feature").

In the first stage, the characteristics of the garden (list of features that represent objects or their layout) are described and assigned to the garden design style. The determination of the features of each style was divided into 4 most important thematic groups:

- layout of the garden alleys, description of location and mutual relations between the elements of the garden composition,
- flora elements,
- water elements,
- garden architecture elements.

The next step was to select the key features of each style, including the indication of repetitive and unique features. From among all the features of each style, we chose the most important ones (key features) that determine its unique character. We selected those features based on the above four thematic groups. Some of the selected key features are repetitive for several styles, while others are unique to one style.

At the stage of classification, hierarchization and generalization, key features of styles are assigned to the map at I level. From the remaining style features were chosen those that could be presented in II and III level maps. The features have assigned weights that determine levels of details indicating on which map levels they should be presented.

The factor determining the number of features on each map was the maximum allowed number of unique cartographic signs allowed on a single tactile map sheet. Considering the generalization of features between styles and the presence of many features symbolized as points, it was assumed that we could slightly exceed the numbers suggested in the literature [31–34]. We grouped features from different styles that have similar meaning into four thematic groups. On I level maps only the key features of each style are presented. II level maps contain all the elements from the I level map for a given area along with all the remaining elements that were originally generalized on the I level map. In addition, the content of maps should be enriched by more detailed elements characterizing the styles, considering the adopted weights of the characteristics and the permissible total number of elements on a map sheet. This solution made it possible to use a selected range of content also on maps depicting other fragments of the garden in the same design style at the same level of detail.

In case of III level maps, the focus was on the features that rarely are repeated between styles due to the unique nature of each of the presented areas. Maps at this scale should present details of unique objects as closely as possible, applying generalization only for the purpose of better legibility of tactile maps.

The catalogues of features at each level of detail

Separating the reference features from the elements of the thematic content is difficult in case of maps of historical gardens. This is due to the specificity of such maps in which all the elements of the content make up the composition of the garden and determine its style. General geographical elements used in classic thematic maps as elements of the background content (e.g. roads, water) play an important role in the composition of the garden. They are also inseparable elements of a specific style. Types of alleys and their layout form the foundation of the garden complex in each of the discussed styles. The same applies to types and shapes of water elements.

The catalogue of features for all garden styles of the I level maps is presented in Fig. 9. To create a tactile map of a garden in a selected style, appropriate features have to be selected from the catalogue. Since this map type presents the whole garden composition, then the dominant features are those related to the garden layout. The UML package diagram used for Fig. 9 refers to separate thematic groups. Each package is characterized by the most important types of features that could exist in the historical garden in different styles.

The catalogue of features of the II level maps is presented in Fig. 10. In the "arrangement" thematic category the same features are assumed for the II level map as for the I level map. The additional class diagram ("class Flora_II") presents the UML classes derived from the UML package of Flora_I (i.e. "Flora_I::Short) and feature types defined for the II level map (i.e. "Lawn" and "GardenParterre"). All other elements are copied from the

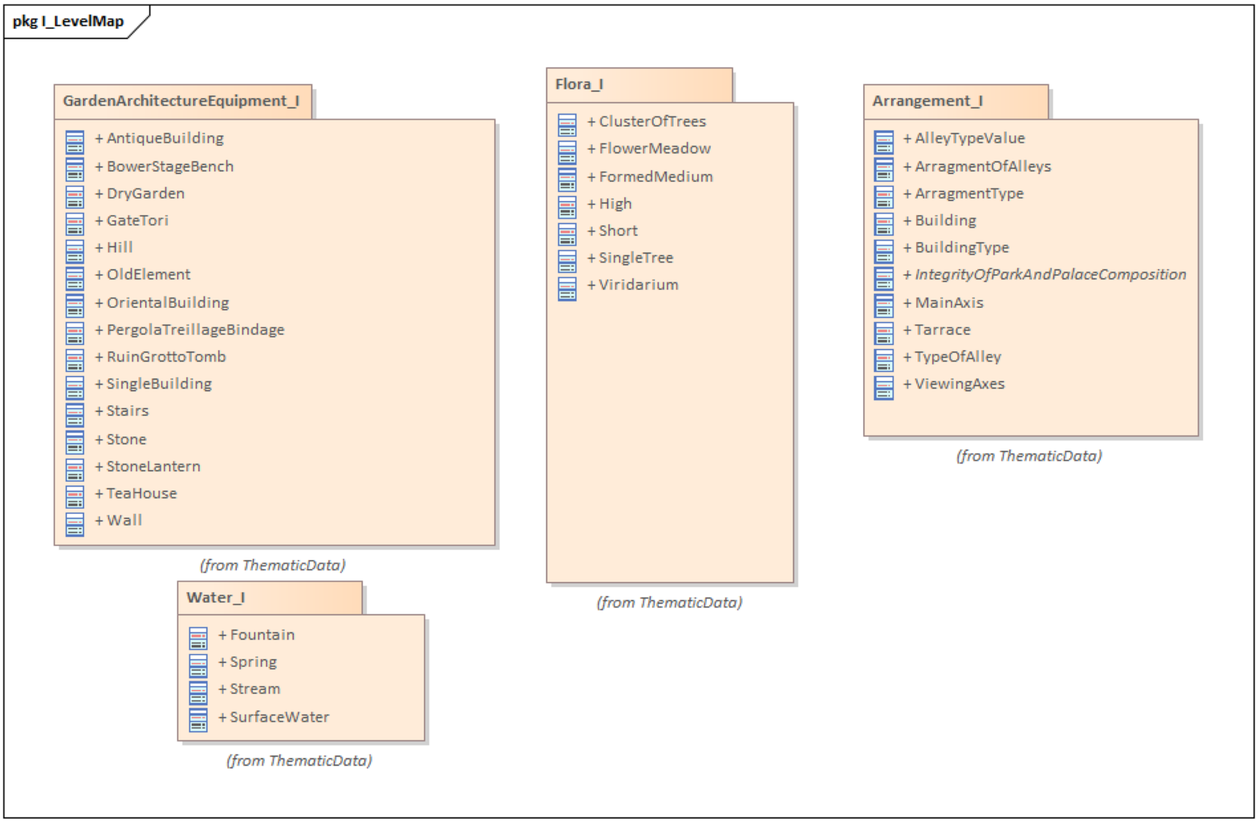

Fig. 9 The catalogue of features for I level maps (UML package diagram)

I level map and extended by additional features: row of shrubs, a single formed tree, a single formed shrub, row of trees. In the Flora_II class diagram there is also the geometry attribute defined for each class (i.e. "geometry: GM_Surface"). This attribute plays the essential role in the process of their representation on a map. Geometry types used for this attribute ("GM_Point", "GM_Curve", "GM_Surface", GM_Object") are derived from the ISO 19107 [39].

The "water" thematic category for the II level map has been extended by a bridge and a waterfall in comparison with its content on the I level. "Garden architecture and equipment" was extended by: antique element, bucket plant, sculpture.

Figure 11 presents content of the maps on the III level. Within the thematic category "arrangement" only the type of alleys was taken into account. In the "flora" thematic group the category of short flora contains: low shrub/hedge, flowers, row of flowers, lawn, medium formed flora, herbs, formed single shrub, formed single tree, strip of lawn. In the "water" category, only fountains were preserved, whereas for the thematic category "garden architecture and equipment" only sculptures and stones were taken into account. In addition, the map content was extended by sand and gravel features.

The tactile maps content scope in the Baroque design style

Based on the rules presented in chapters 3.1–3.3, the tactile maps content scope for all five garden design styles was defined (Appendix). Each map is created by selecting the appropriate elements from the catalogues of all elements presented in Figs. 9, 10, 11. To better illustrate this process, the content scope of the tactile maps in Baroque design style is presented and discussed in this chapter as a case study.

Figures 12, 13, 14 show the content scope of tactile maps for the selected mapping areas in the Baroque style. We used the UML class diagram to present the concepts. First, features from each package for the I level map were selected (Fig. 9) and are specific to the Baroque style (Fig. 12). Then, the features for the II level maps were selected based on the classification presented in Fig. 10. The content range for the Baroque design style map at this level also includes selected elements from level I (Fig. 13). To define the content scope of the III level map, the feature types defined in the III_LevelMap *package*

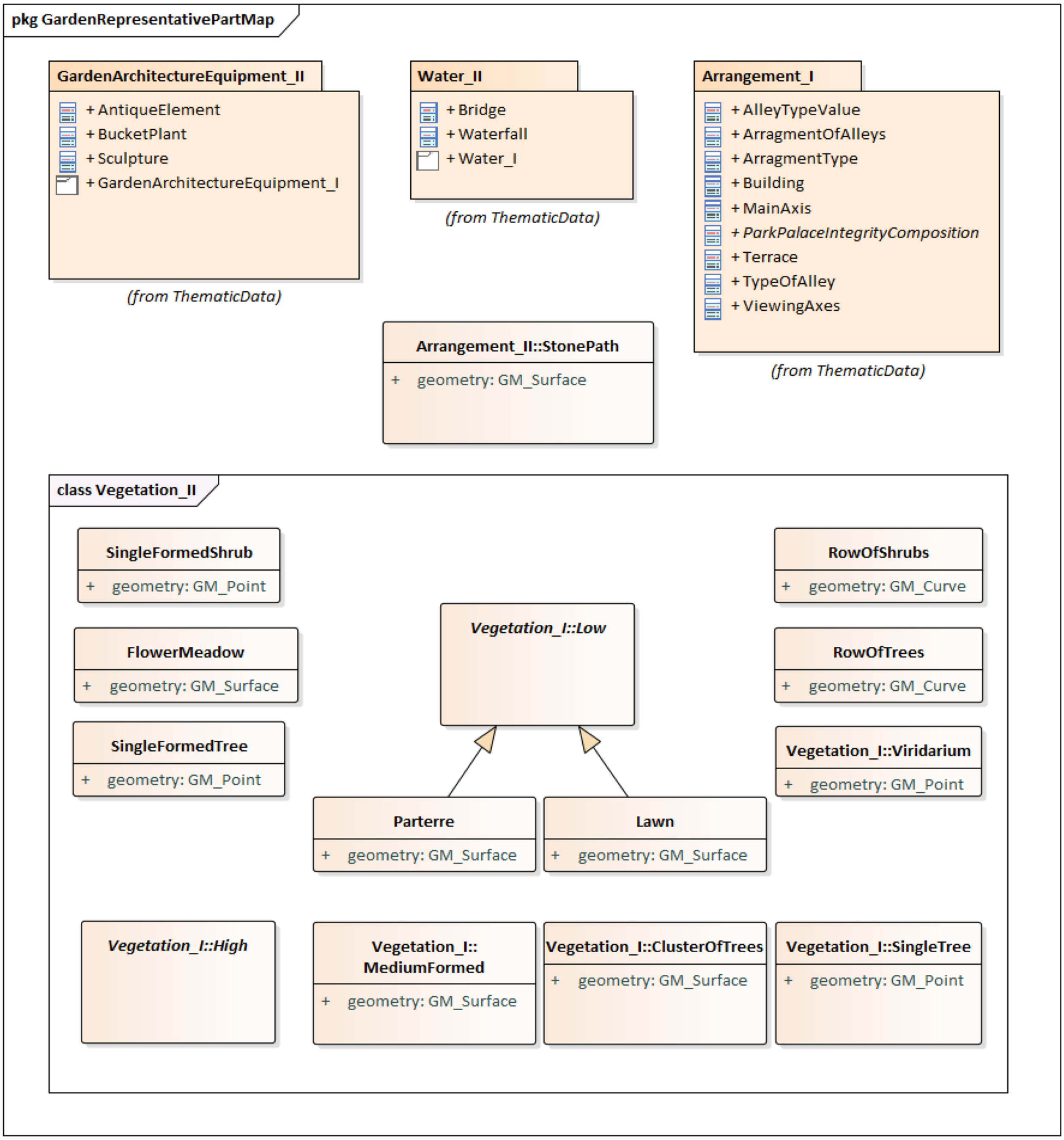

Fig. 10 The catalogue of features for II level maps (UML package diagram)

were selected. Figure 14 shows the content scope of this map in the Baroque design style.

In Figs. 12, 13, 14 in the classes Arrangement_I:: TypeOfAlleys and Arrangement_I:: ArrengementOfAlleys the attribute "type" was defined. The classification of alley types and arrangement shows classes with stereotype < < CodeList > > ("Arrangement_I::AlleyTypeValue", "Arrangement_I::ArrangementType"). The appropriate values for each map level are shown in the UML notes linked to the selected class in each diagram. If a class is a subtype of another one, it is then presented in the form of name in italic in the right side of the upper section of the class (i.e. "Flora_II_GardenParterre" in Fig. 14 is a subtype of "Flora_I::Short", Fig. 10).

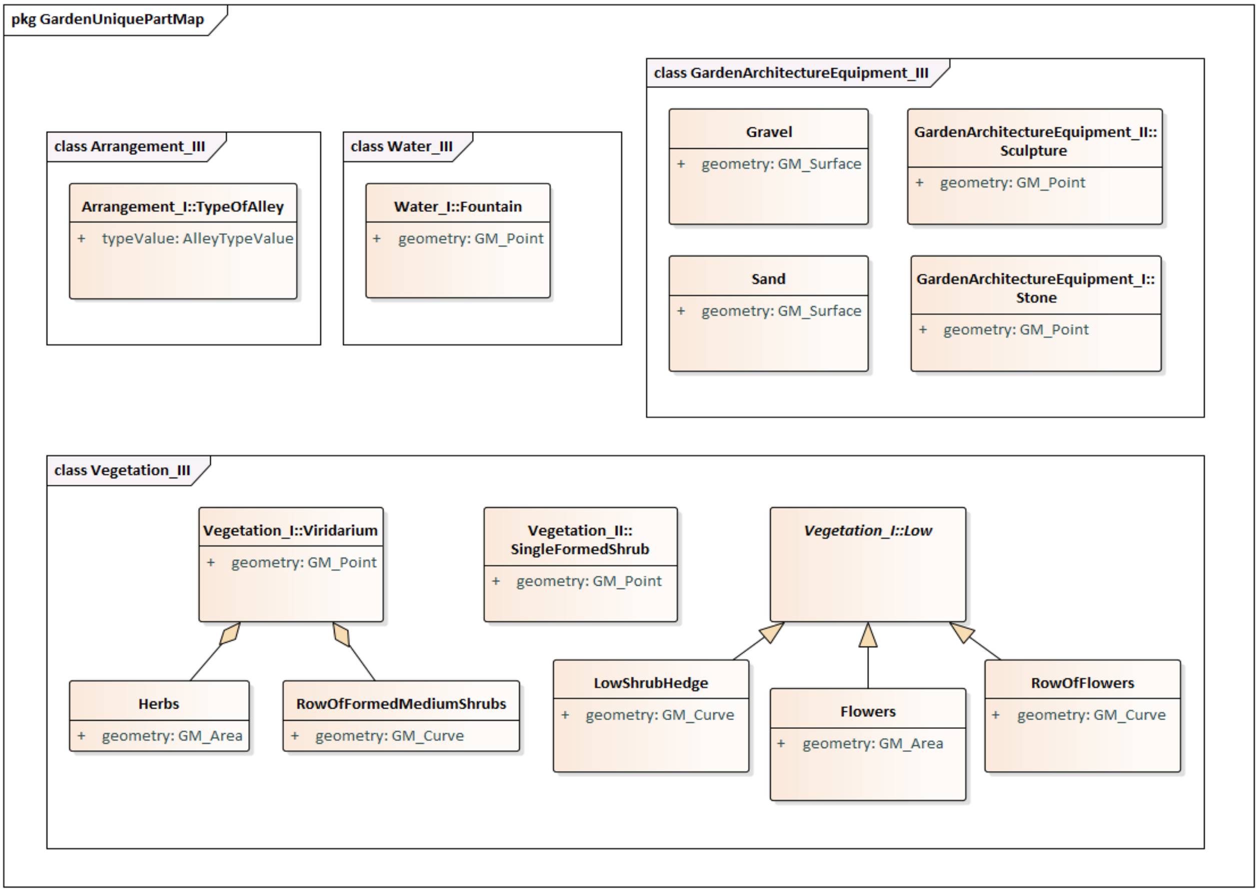

Fig. 11 The catalogue of features for III level maps (UML package diagram)

Discussion

The research presented forms the first step towards the methodical development of tactile thematic maps, covering one of the types of immovable monuments, i.e. historic gardens. The complexity of this task is due to the need to combine cartographic and garden architecture knowledge as well as PVI perception limitations.

Moreover, the literature on this subject does not provide analogous solutions in the field of garden mapping (neither classic nor tactile), nor in the related areas. Tactile maps developed so far have focused only on content for orientation and mobility and not on features representing particular garden design styles. Besides, these maps were not developed according to the uniform rules, so each map is different and in result, their development is time-consuming and expensive.

Therefore, we divided the research on this topic into two parts: the conceptual part presented here, and the implementation part, which is a work in progress. Apart from that, a separate broad aspect is the issue of low-cost printing of tactile maps that could enable wider availability of such maps for PVI. The impact of inappropriate production technique selection on the reduced availability of legible tactile materials has been raised in numerous previous research (e.g. [15]). The increasing popularity of 3D printing and its rapid development may eliminate such problems in the near future. 3D printing not only enables low-cost printing and rapid prototyping, but also allows almost unrestricted possibilities in terms of tactile signs design. It opens up opportunities for the development of new concepts in terms of increasing readability and conveying more information through tactile maps and graphics [42, 43]. It should also be mentioned that the use of modelling and 3D printing is also becoming increasingly popular in the digital recording of cultural heritage elements [44].

We want to highlight the fact that the presented topic forms only a part of the very wide, holistic research on methodical tactile mapping of historical gardens, covering all stages of their development.

The presented concept is a starting point to mapping historical gardens with a focus on learning about garden

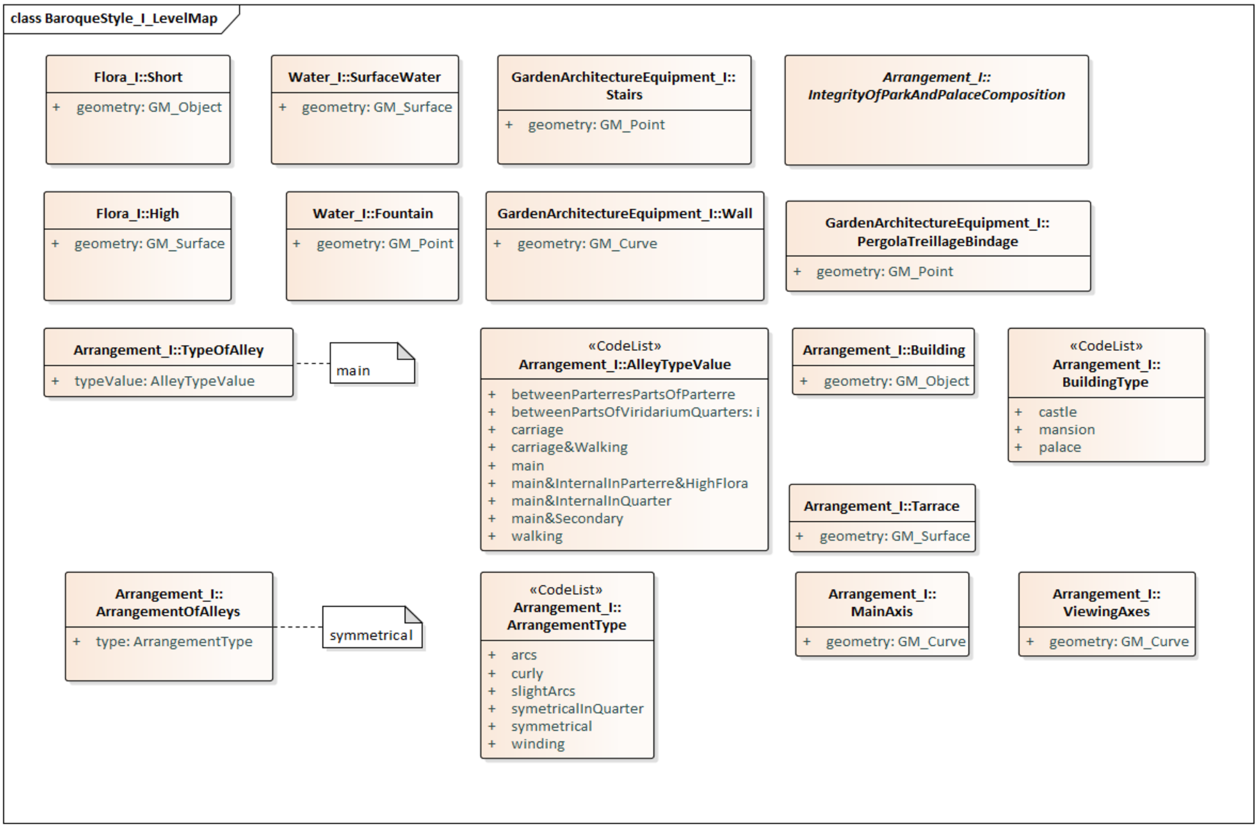

Fig. 12 A content scope of the I level map in the Baroque design style (UML class diagram)

styles. The existing solutions not only did not present garden design style features on the maps but they were also developed without methodological basis and rules enabling repeatability and quick creation of products for PVI. The advantages of our solution in relation to the previous garden tactile maps are summed up in Table 3.

The key results of our research show that garden compositions in various styles can be presented on tactile maps and to provide PVI with a new type of thematic maps, developed methodologically. The developed methodology draws on the fundamental principles of the map elaboration, while corresponding to the principles of tactile maps design. We provide the solution for how to map gardens on tactile maps.

Moreover, we have developed catalogues of features and ready-to-use lists of tactile maps content elements. This achievement brings the answer to the first research question. The proposals presented in this paper fill the gap in the scope of studies intended for PVI, with cognitive values regarding forms, functions and meanings of elements of small garden architecture, plant arrangement and the garden composition. Using our approach can improve the accessibility to this type of cultural heritage for people underrepresented in society, thereby reducing the extent of their informational exclusion.

Selecting the most significant features of the most popular garden styles, their classification and hierarchization on various levels of map detail as well as their generalization to a form legible by PVI are also important advantages of this research. These rules were developed by a team of specialists: cartographers, special educators and garden art specialists, thanks to which they consider all the aspects necessary for the correct preparation of fully-fledged product for PVI. However, the proposed catalogues of features for specific garden styles give the opportunity to develop maps of gardens, without specialist knowledge in the field of garden architecture.

It should be underlined that we consider the use of the UML to describe the proposed solutions as one of the major advantages of the proposed solutions. Formalizing the principles of content selection in the form of the UML activity, class and analytical diagrams allowed us to describe the concepts in a universal and convenient way for analysis. It also allows for further modifications and development of methodological assumptions and

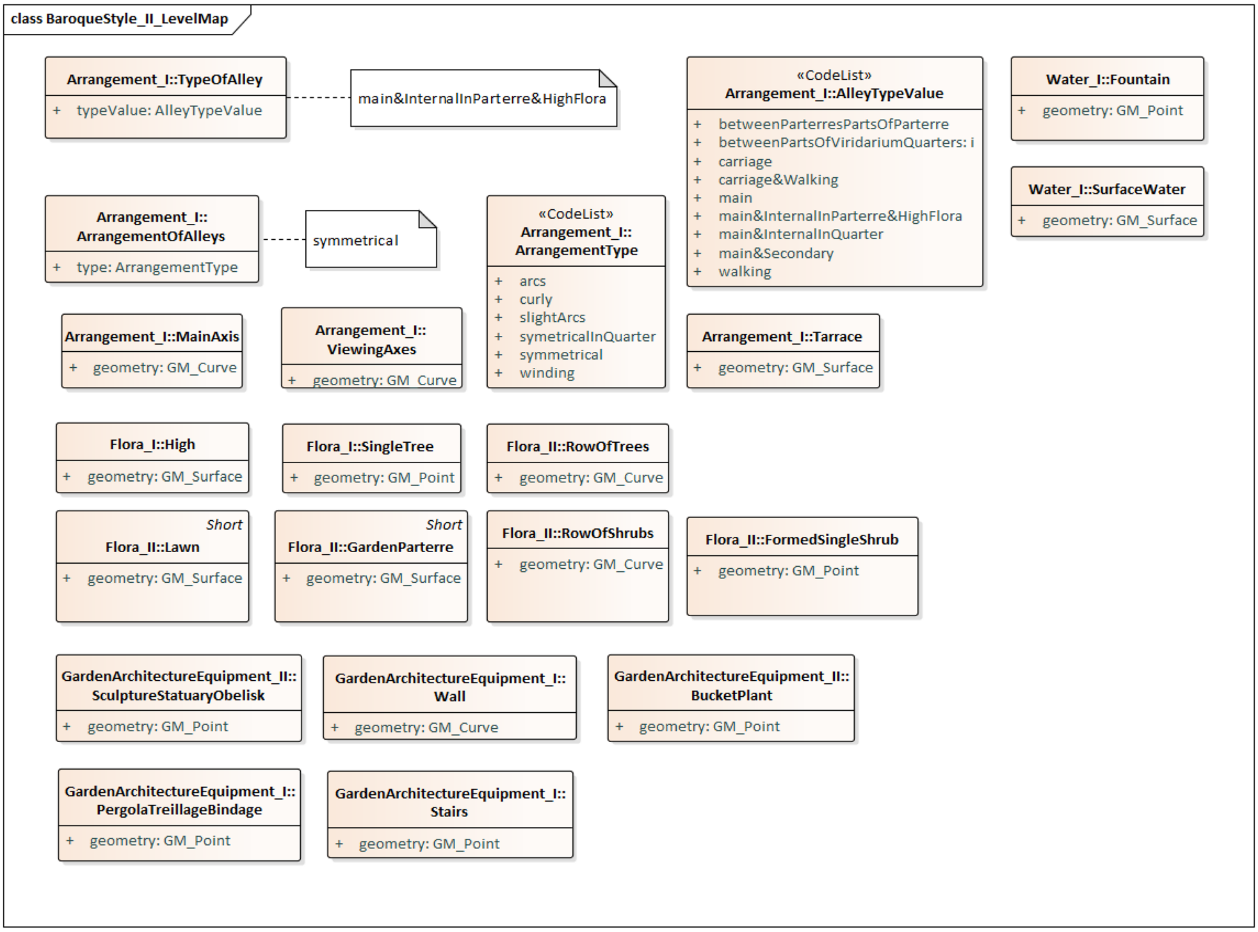

Fig. 13 A content scope of the II level map in the Baroque design style (UML class diagram)

formulation of new rules, as well as adding new garden design styles. The formalized description of the process presents the principles of selecting the content of tactile maps in an unambiguous way and allows the same understanding of the universe of discourse by each of the recipients.

Using UML allows the implementation of the adopted concept in any technological solution (e.g. in any software used in geospatial solutions) in the form of a spatial database structure for the purpose of a garden map development. This structure is ready to be filled with data for any garden in one of the five styles, which were analyzed in this study. Our approach makes it easier for cartographers to develop tactile maps and speeds up the entire mapping process. It also ensures the repeatability of the content ranges of tactile maps of historical gardens, making it easier for PVI to perceive them.

All the above provides us with the answer for the second research question—all aspects of our results can be described in UML—from the mapping area selection, through the process of content selection, to the catalogues of features at each level of detail for every design style.

The formalized description of the solutions proposed in this study meets the activities in the area of standardization of the tactile maps development process. Previous works in this area mainly included standardization of the principles of the character design [21] or spacing between signs on maps [45]. Standardization and formal description of the mapping process is not present in the subject literature, especially the rules for the content selection. This problem mainly concerns thematic tactile maps [46, 47].

One of the limitations of the presented research is the inclusion of only five garden design styles in our research. Besides, we offer solutions only for gardens in which the original style of composition is preserved on a significant level. However, many existing gardens have been rebuilt or altered many times over the years of their existence so they rarely contain only the features from the original

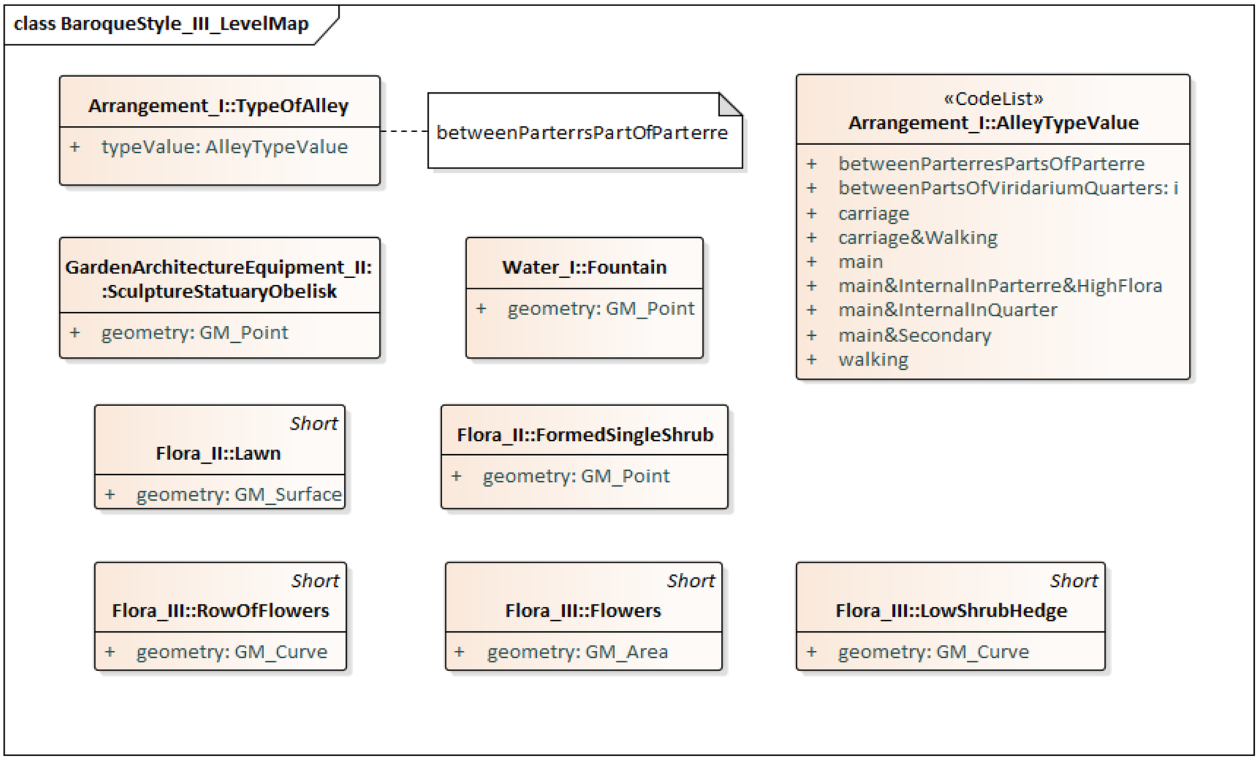

Fig. 14 A content scope of the III level map in the Baroque design style (UML class diagram)

Table 3 Differences between our solution and the previous garden tactile maps

Features	Previous tactile maps of gardens	Our tactile maps of gardens
Map type	Navigation and mobility maps	Thematic maps
Garden design style features	Not present	Present
Similarities/differences of garden styles	Not applicable	Present common/unique Style features
Content selection method	Unmethodical	Methodical
Content selection area	Single map	Set of maps
Cartographic signs design	For a single map	For the set of maps
Map design	Unrepeatable	Repeatable
Formal description	None	UML

style. In such situations, it is possible to use our tactile map content selection procedure and proposed mapped areas, but the catalogue of objects at specific levels of map detail will not always apply. In such cases it seems reasonable to carry out the classification and generalization of features from scratch, taking into account the features of all styles present in a given garden. Nevertheless, in our opinion it is first necessary to introduce PVI with gardens in only the five discussed styles and later, potentially, expand this knowledge with further, more complicated cases.

Conclusions

The study presented in this paper addresses the issue of developing garden maps dedicated to PVI in various design styles. The proposed methodology includes rules for developing the content of tactile maps as well as the classification of content features and the rules for determination of the mapping areas. The basic methodological components are presented in the form of conceptual models in the UML notation.

Most existing tactile maps focus mainly on the location of specific features, including the location of cities, rivers or geographical lands. They are designed to present very basic features of space, serving mainly for spatial orientation and navigation. The concept described in this study aims to transmit cultural values that, through immovable tangible heritage like historic gardens, convey intangible assets, such as building respect for the past, appreciating the artists' works, recognizing the achievements of the past generations, and learning about national and world heritage.

The study also contributes to the formal way of describing cartographic aspects in the tactile cartography domain, such as the conceptual and editorial stage of maps elaboration through the use of UML diagrams. The models present features of the historical gardens, for the purpose of one particular cartographic visualization type—tactile maps. These features could be presented on national and global levels.

The future research plans include developing prototypes of garden maps and testifying them by PVI. The target maps will be prepared in the standardized formats (not exceeding the dimensions of the A3 format), using the sets of tactile and graphic signs verified in an iterative process by the group of 20 PVI in controlled study sessions that have been carried out by our research team in the past. During these sessions we have introduced empirical real-world scenarios to avoid biases raised in several works that derive from inappropriate evaluation of the proposed approaches to tactile maps design (eg. [48, 49]). The materials used so far were produced using 3D printing and swell paper techniques due to the ability of rapid prototyping they allow. Based on the study participants feedback, the 3D printed plastic maps were legible and comfortable to use. Nevertheless, we have scheduled additional tests to verify the utility of different materials (e.g. metal and rubber) and production techniques (e.g. CNC milling and molding casts).

The tactile maps, based on the presented methodological assumptions, may contribute to a change in the approach to visiting gardens by PVI and increase their independence while exploring the historic spaces. A user of such a tactile map can get to know the garden before visiting it, and get acquainted with its features and values. This can result in the greater openness to new places and the desire to participate in social life, as well as a sense of their own comfort and safety while visiting the garden, thus increasing their inclusiveness.

Appendix

The tactile maps content scope for Renaissance, English, Romantic and Japanese garden design styles.

See Figs. 15, 16, 17, 18, 19, 20, 21, 22, 23, 24.

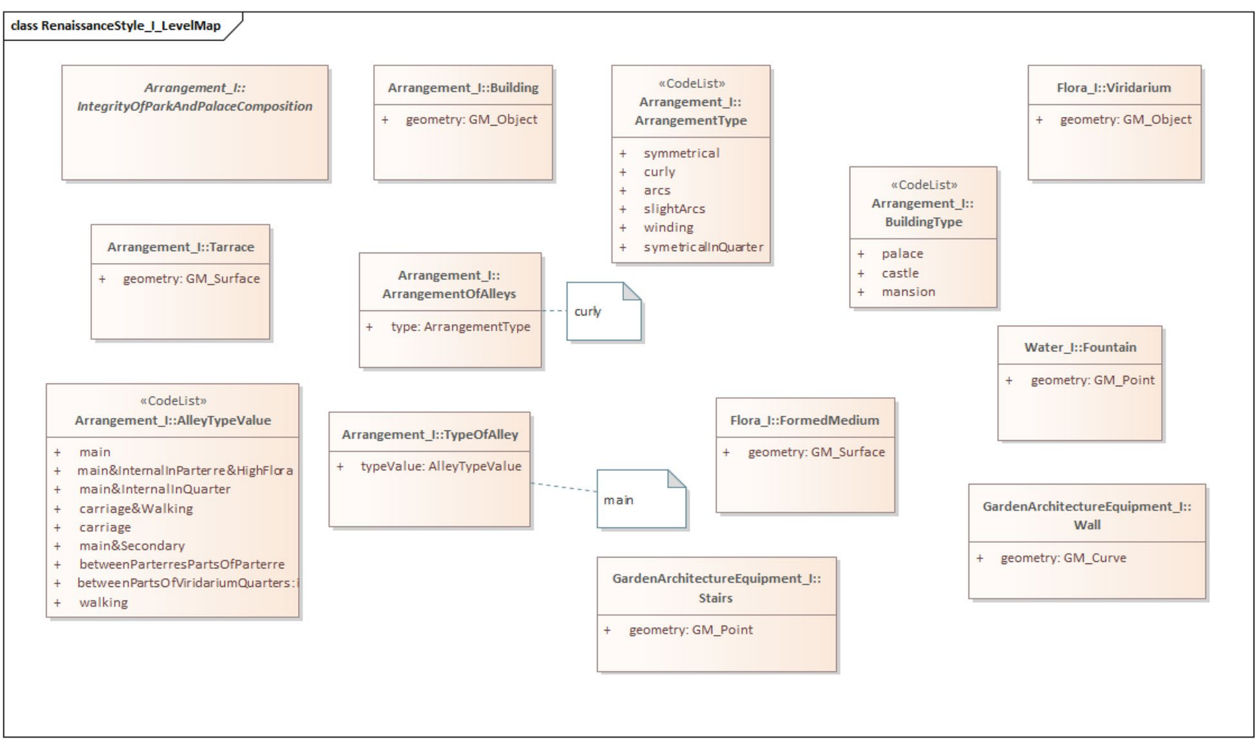

Fig. 15 A content scope of the I level map in the Renaissance design style (UML class diagram)

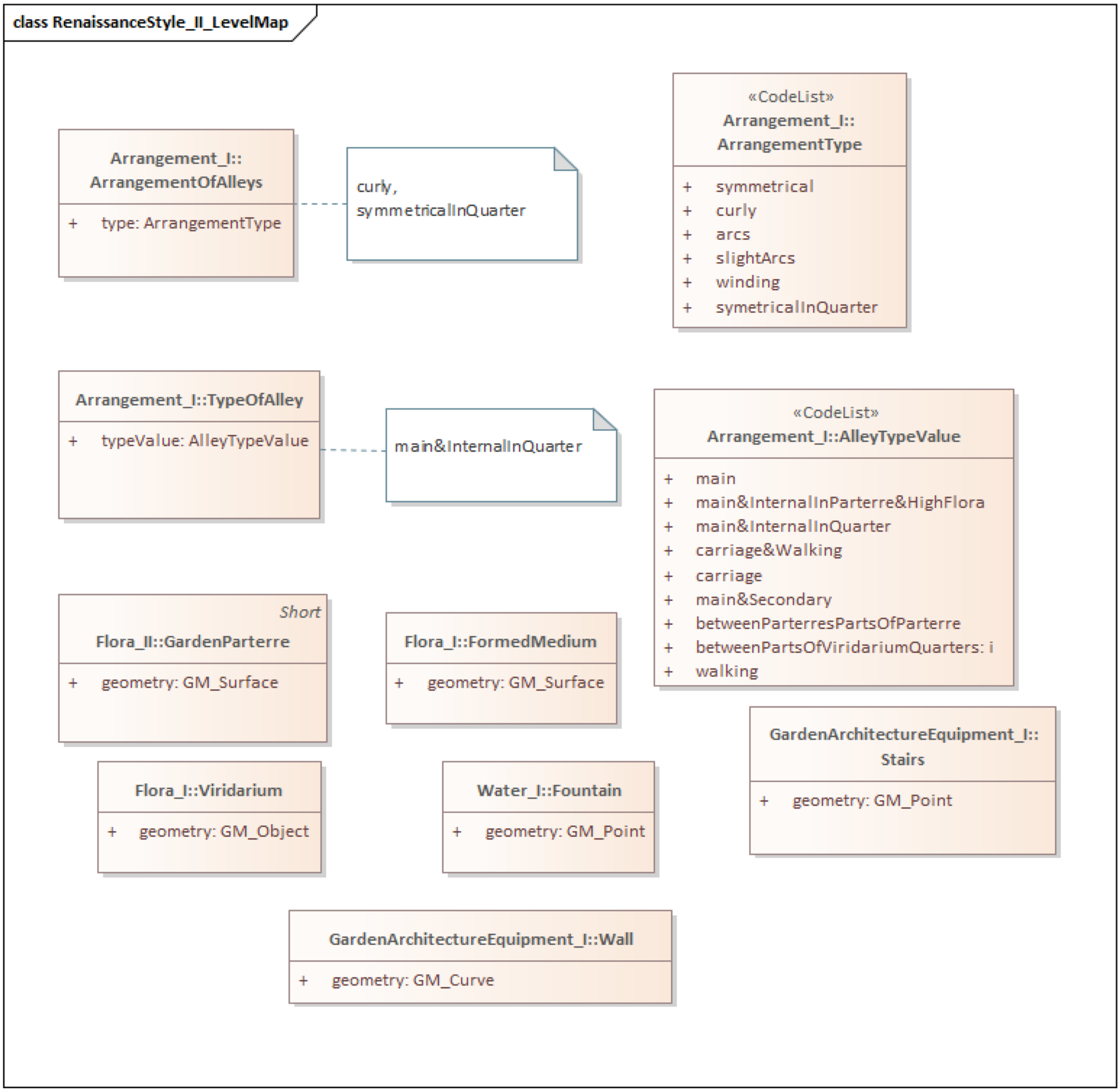

Fig. 16 A content scope of the II level map in the Renaissance design style (UML class diagram)

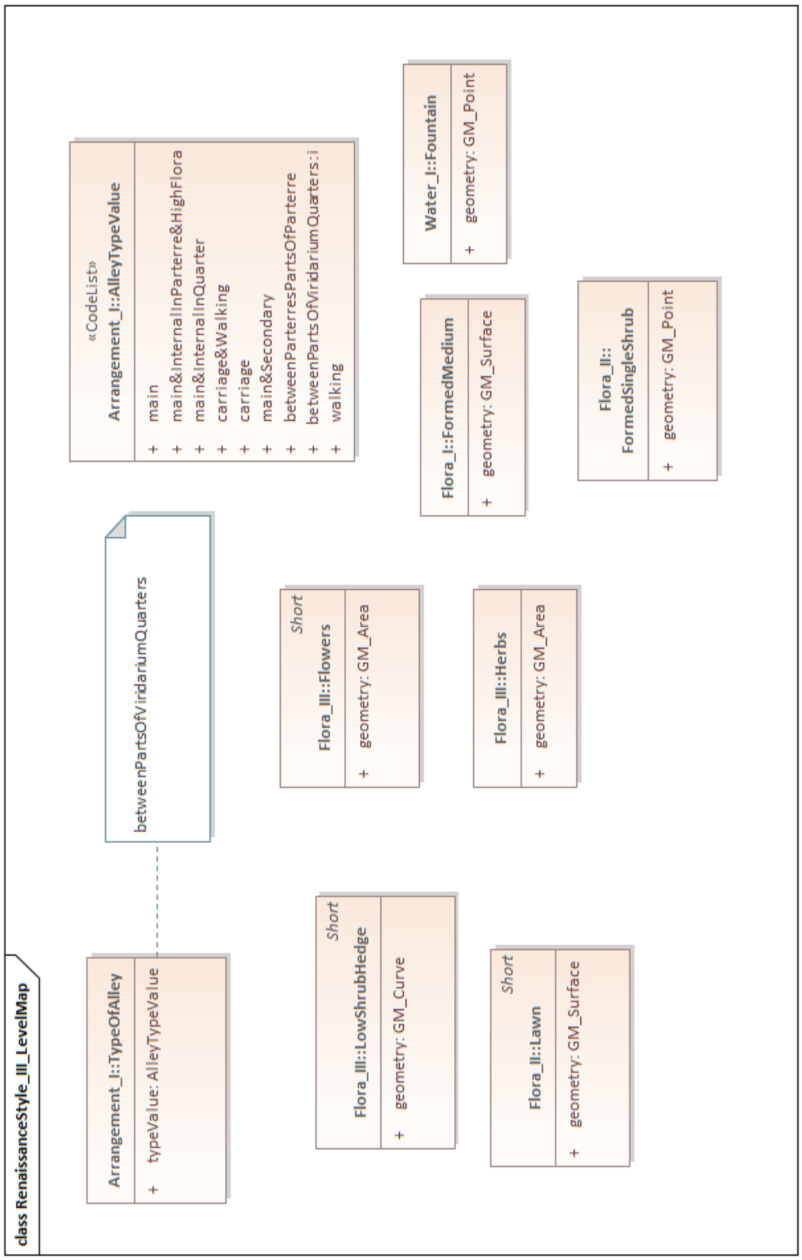

Fig. 17 A content scope of the III level map in the Renaissance design style (UML class diagram)

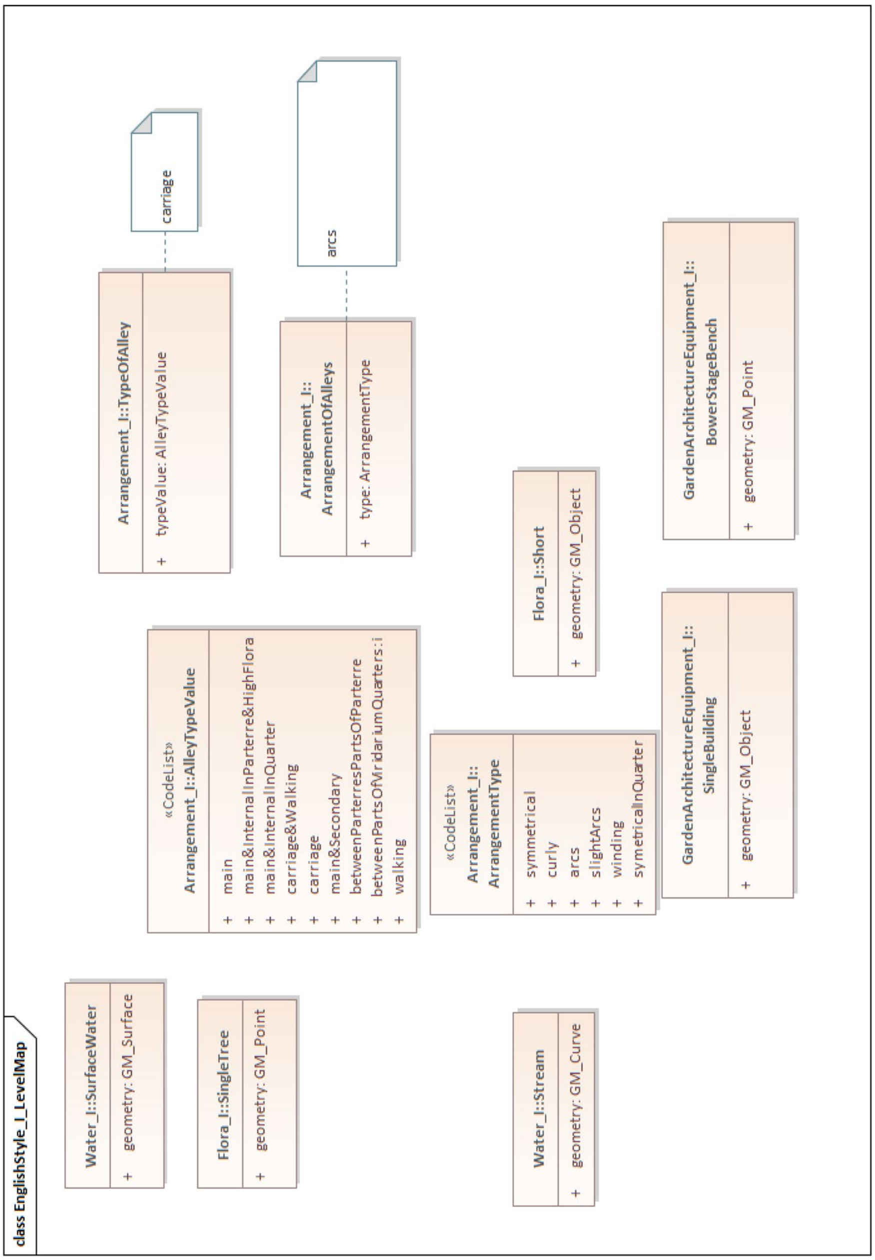

Fig. 18 A content scope of the I level map in the English design style (UML class diagram)

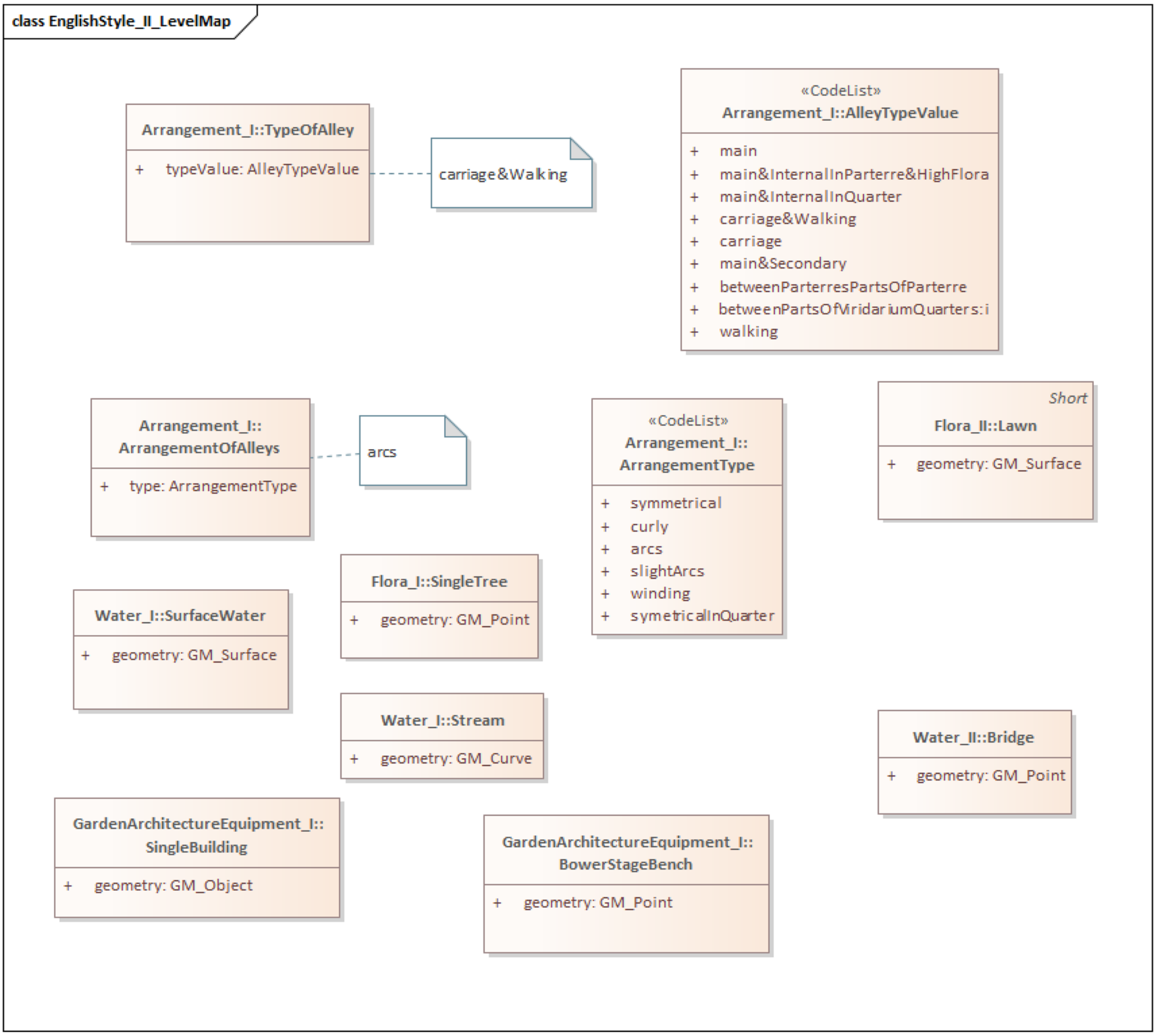

Fig. 19 A content scope of the II level map in the English design style (UML class diagram)

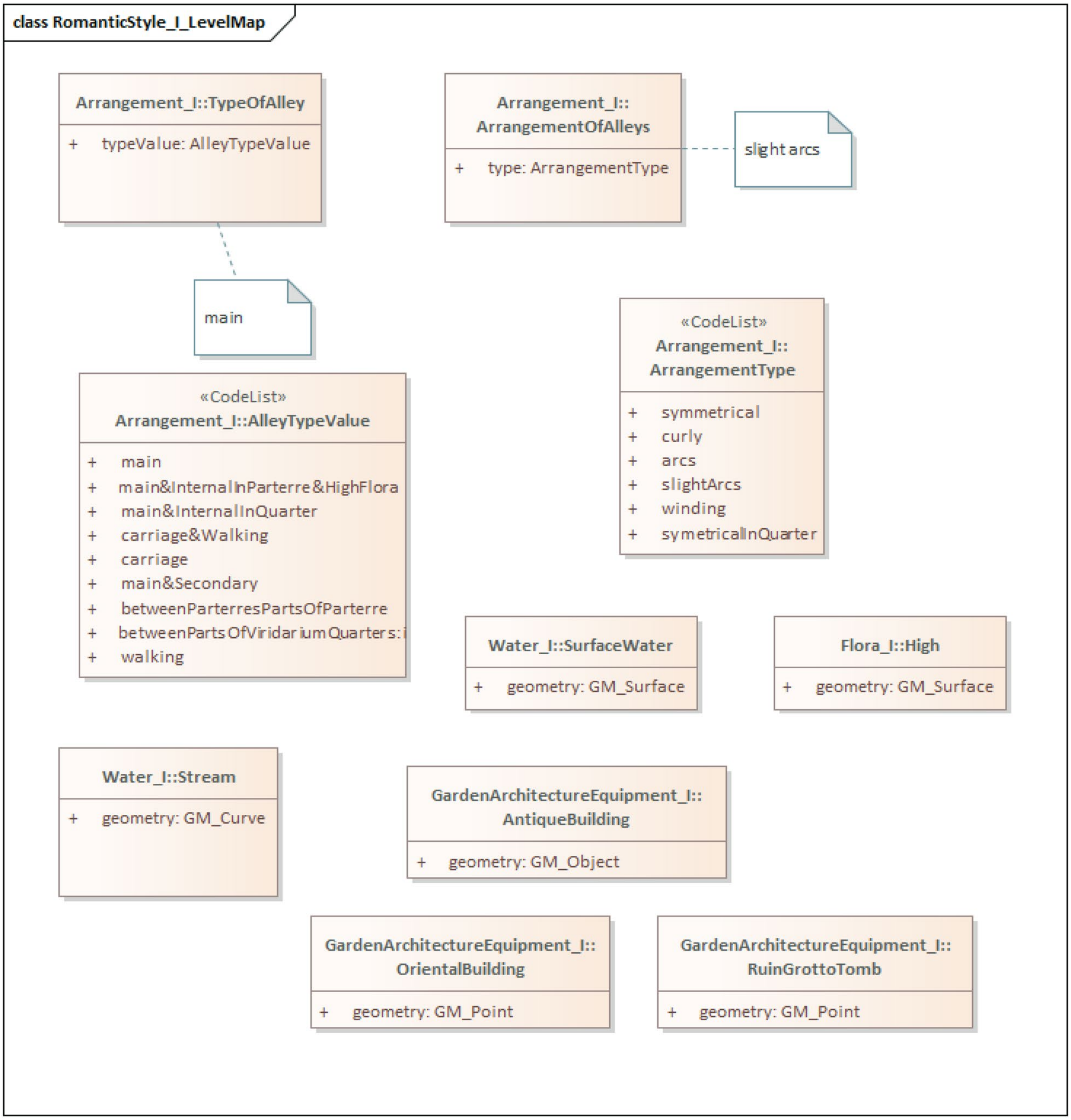

Fig. 20 A content scope of the I level map in the Romantic design style (UML class diagram)

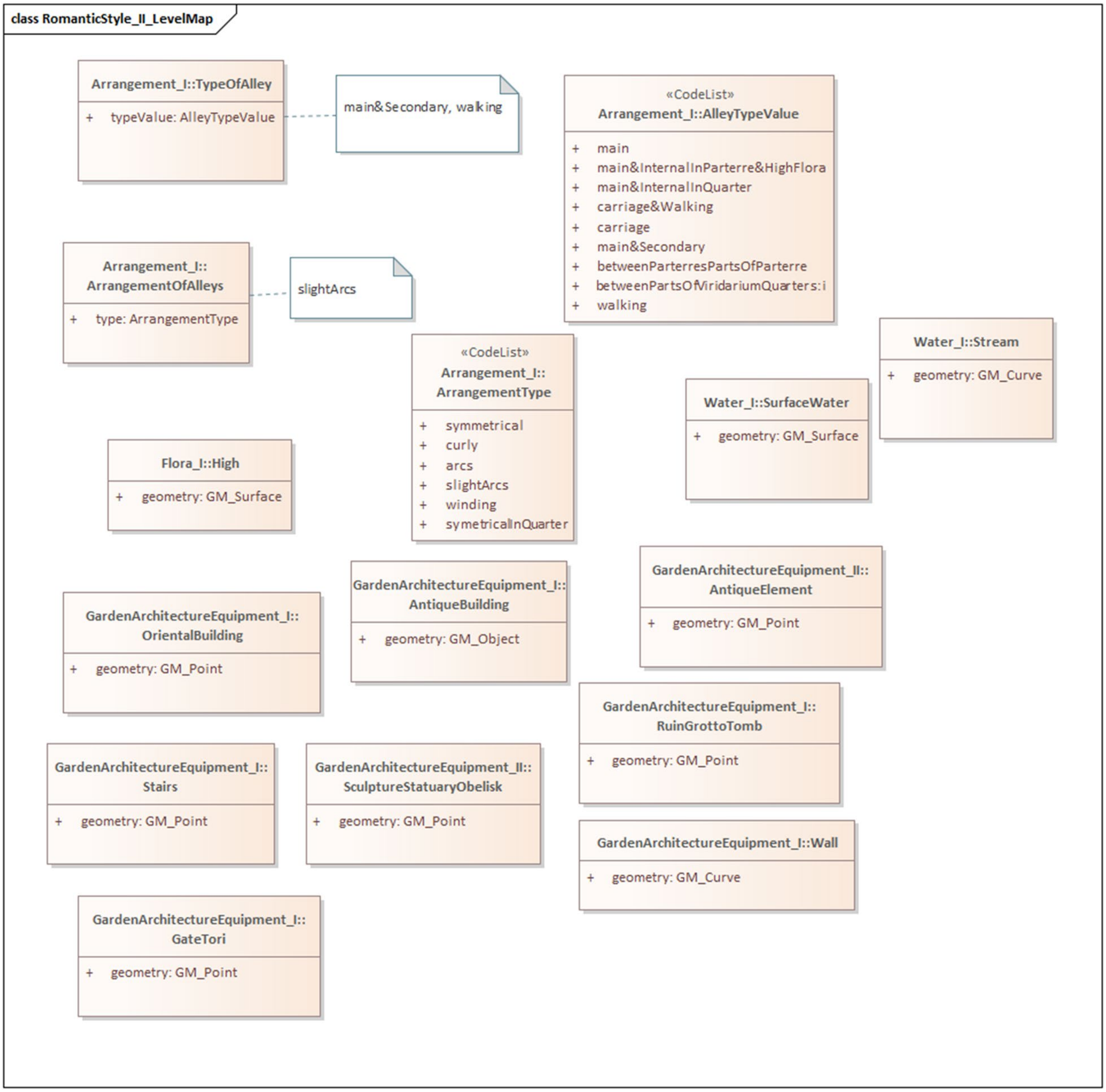

Fig. 21 A content scope of the II level map in the Romantic design style (UML class diagram)

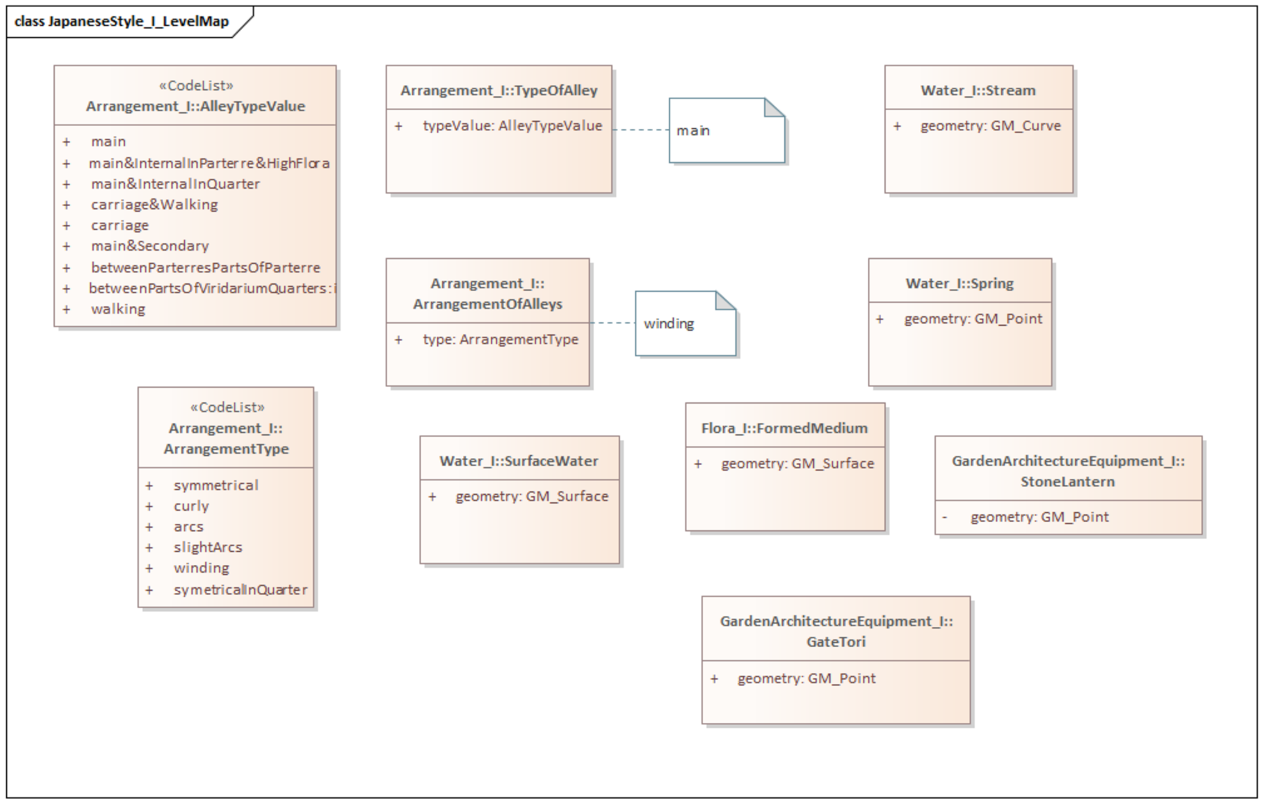

Fig. 22 A content scope of the I level map in the Japanese design style (UML class diagram)

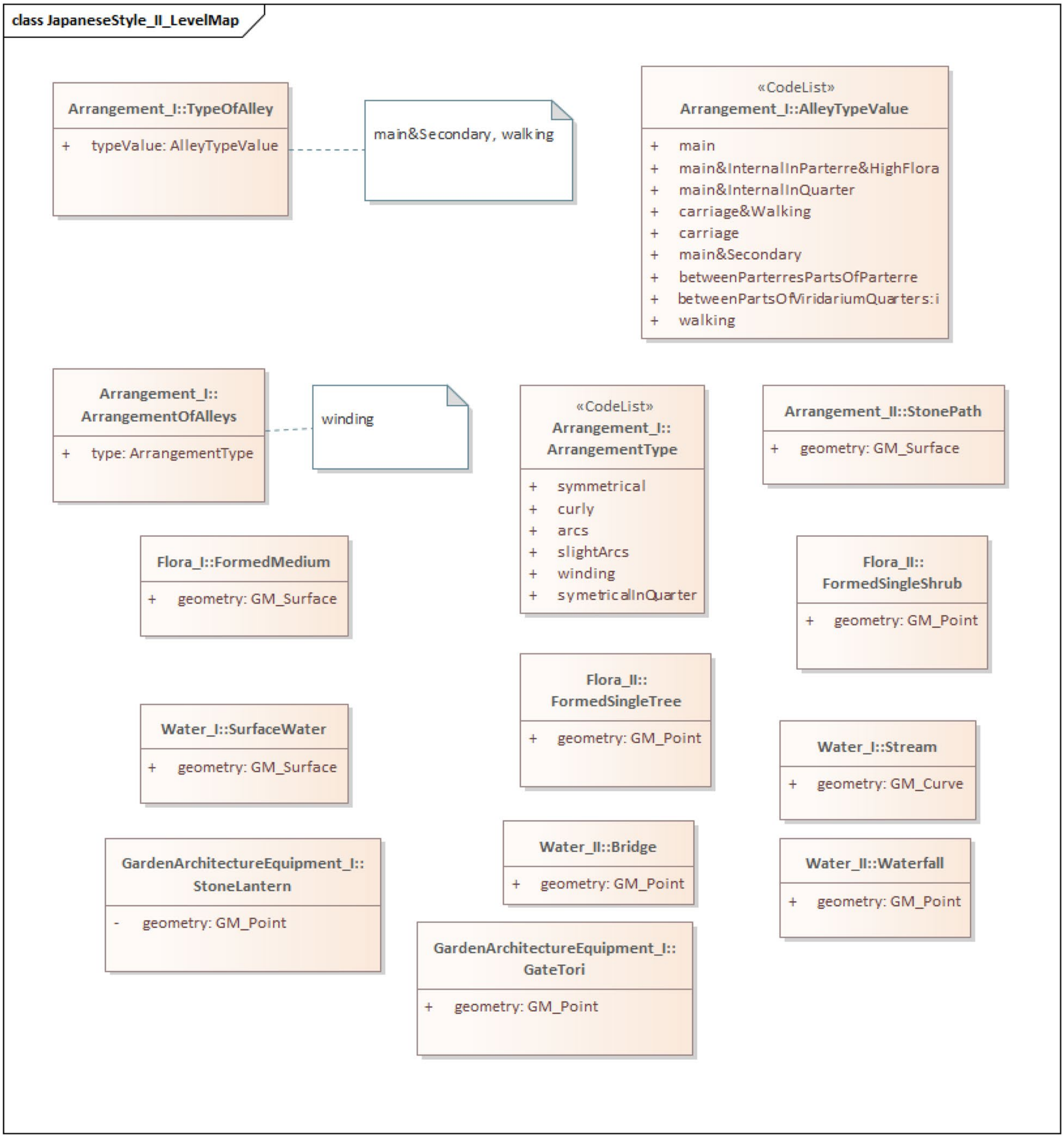

Fig. 23 A content scope of the II level map in the Japanese design style (UML class diagram)

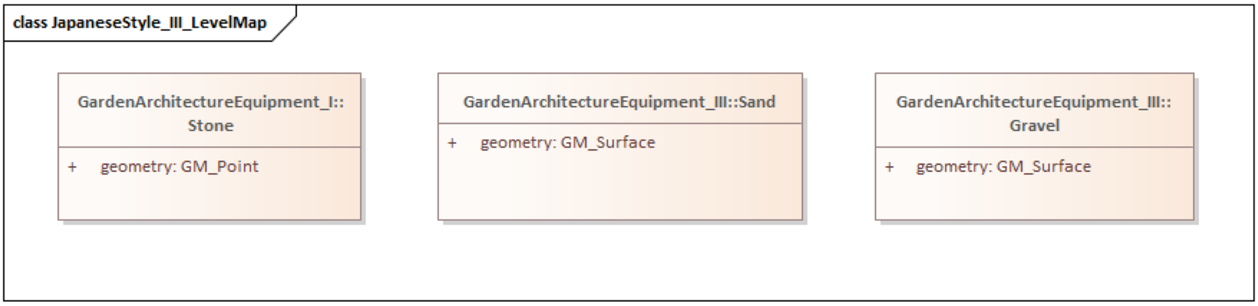

Fig. 24 A content scope of the III level map in the Japanese design style (UML class diagram)

Abbreviations
PVI People with visual impairments
UML Unified Modeling Language

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Author contributions
Conceptualization, methodology: AM, AZR, AA, JW, DK; tactile map content development: AM, AA, JW, DK, AZR; formal description in UML, writing—original draft preparation: AZR; writing—review and editing: AM, JW, AA, DK; supervision: AM. All authors read and approved the final manuscript.

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Not applicable.

Declarations

Competing interests
The authors declare that they have no competing interests.

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