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Arch-creating Software

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Abstract. The arch is an important architectural design element. Its production can be a long and tedious process of design, calculations, drafting, adjustments, construction drawings production and other tasks. This paper establishes the foundations for arch-creating software that reduces the time needed for producing the arch and enhances the quality of the arch designed by allowing a wide variety of arches for the architect to choose from. First, it defines the full range of arch types which it will cover, finds the common parts that are shared by sub-groups of these arches as well as the singular parts, applies the historical concepts of distortions (an approach that enabled this paper to create totally new types of arches as one of its major contributions to this field), defines the variable set for each arch type, and discusses its relevant geometry. Finally, it decides on the most suitable environment for such a program. Due to the fact that an arch is only a part of an architectural drawing, there was a need for an environment that provides capabilities to draw the other necessary parts and to which the arch program can be integrated. This dictated the AutoCAD environment, which provides both a programming language (AutoLISP, which is a special dialect of the Lisp language) and the ability to draw any item needed. All of the arch drawings presented in this paper were created via software written according to the basis it establishes. These play the role of a proof to the theory of the paper.

1. Introduction

Throughout history the arch had been an important architectural element both in terms of elevation design and as a structural element. The earliest known arch of a curved profile was found in Iraq as early as 4000 B.C. [1, p.263]. There are many types, some of which were associated with certain civilizations. An example is the round arch which was the major arch used by Roman architects. Another example is the four-centered arch which was developed by the Muslims as a variation of the pointed arch, both were later associated with Gothic architecture.

Although in the twentieth century the arch lost its constructional importance - which was to span openings too large for a single member, where metal is now used- it is still considered an important element in modern architecture both in the facade and as a roofing (vaulting) system. Its importance varies from one region to another according to the local materials at hand, and the cultural heritage.

2. Needs and Advantages

The purpose of this paper is to describe the design of an algorithm of arch-creating software. The advantages and needs for such a program can be summarized in the following points :

1. Reducing the time taken to draw a single arch.
2. Exposing the designer to a very wide variety of arch types from which he can choose. This variety ranges from the most common types to rare types, and from old to new.
3. Enhancing the final quality of the arch designed through providing many alternatives for a single design.
4. Creating new types of arches that never existed before through applying procedures that were only restricted to limited types only.

3. Definitions

At first a general definition of the arch will be presented. One of the best definitions is that given by the *Encyclopedia Britannica*:

"[Arch] is any combination of bricks, stones or other building material generally wedge-shaped and with radial joints, used to span an opening. The common profile is a curved line, although many variations exist. By extension, the word arch is used for any curved head of an opening, even when the material is homogeneous, as in a concrete or laminated wood arch" [1, p. 262].

The major parts of an arch are: its voussoirs, the keystone, the springer, the intrados, and the extrados. Fig. 1 shows these and other parts.

It should be indicated here that the above definition applies to the "true arch." Other arches that are not quite "true" are the corbelled arches, where the profile of the arch is obtained by ordering the materials in horizontal tiers on each side of an opening. Each row projects further from the one below until the two sides meet. The final profile will draw the desired arch.

The concern of this paper and the software it presents is the creation of true arch with voussoirs.

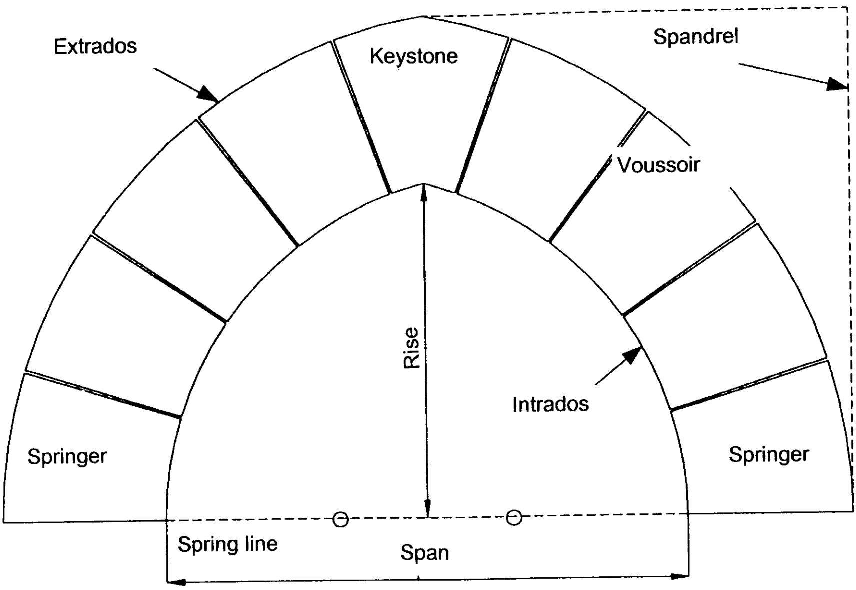

Fig. 1. Elements of the arch.

4. The Design Concept

The first step in creating the program was to define the domain of arch types that it will cover with the variations within each type. The variations common in more than one type were called as procedures, and two were defined (named as Florentine and rampant according to their appearance in the types). Then all types were analyzed geometrically and each type was broken into parts. Some of these parts were found common between many types, others were singular (i.e. found in one type only). Each of these parts was analyzed and its set of variables was defined. A parameterizing process was applied to these parts so as to accommodate for the procedures mentioned above. Thus, each part was described, and its input-output data were defined. Finally a set of variables that are general for all types of arches was defined.

The organization of these modules into the software design will be presented in the coming section, but first the above steps will be described in details.

4.1 Grouping the types

The first step in creating the program was to define the domain of arch types that will be covered by the program. The current choice is believed to cover a very wide range of the known arches, but not all. Other types can be analyzed in the same way and then added. Following is a list of these types with a definition and a brief historical background for each[1] (many of the following descriptions of the types are taken and revised from many sources [1-4]).

Flat arch: (Fig.2-a1) An arch whose intrados is a single straight line with the joints between its stones directed towards a point. The resultant shape of the stones prevents them from falling and gives the arch its load bearing capacity. The flat arch with many voussoirs was devised and used by the Romans. It was derived from the following method of construction: they used to set single blocks of stone with sloping ends over the columns, and closed the gaps between them by dropping in further blocks with their ends cut to fit [5, p.181].

Triangular arch: (Fig.2-b1) An arch whose intrados is composed of two inclined lines meeting at the top-point of the arch. The spanning of a wide opening with a triangular arch of two stones leaning on each other was used as early as the Neolithic age, and was later used by the ancient Egyptians [1, p.263].

Elliptical arch: (Fig.2-c1) An arch whose intrados represents half an ellipse (whether positioned vertically or horizontally). Some researchers also consider the parabolic-shaped arch as elliptical. This type is Sassanian, and an early true elliptical arch can be seen in the palace at Ctesiphon (4th century or 531-579). There the elliptical barrel vault over the hall rose about 36.7m from the floor and covered 25.3m span [5, p.94 and 6, p.52].

Round arch: (Fig.2-d1) An arch whose intrados is a semicircle and it is referred to as such. It is the most basic type of arches from which the definition of the arch was derived. The first true arch was used in Mesopotamia by the third millennium [5, p.19]. In Egypt it was known and used on a small scale as early as the beginning of the Third Dynasty (2680 BC) [5, p. 34].

Segmental arch: (Fig.2-e1) An arch whose intrados is a segment of a circle. The segmental profile for vaults was used in Egyptian architecture, but the true segmental arch was devised by the Romans [5, p.184]. They used it as a discharging arch (an arch built over a lintel of other opening) along with the semicircular arch.

Horseshoe arch: An arch whose intrados-end-points have an elevation less than that of its center. There are three types: *Sestal, listal* and *Islamic* (the first two terms are introduced by this paper to describe different types). The *Islamic horseshoe* arch has one curvature and its joints are directed towards a single point (Fig.2-f1). *The sestal horseshoe* arch also has one curvature but two directions for the joints: Those above the intrados center are directed towards a point, while the joints beneath the intrados center are horizontal (Fig.2-g1). The word sestal is derived form the description of the lower

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[1] It is not the purpose of this paper to provide a historical survey of the arch; the attempt here was to provide the earliest known use of the type indicated.

part of the arch "SEctorial Stones directed Towards A Line". The *listal horseshoe* arch has its part above the center as a curve, with the joints directed towards the center; while its lower parts are straight lines (tangent to the curve) with horizontal joints (Fig.2-h1). The word listal is derived form the description of the lower part of the arch "Linear Stones Directed Towards A Line".

Although there are few examples (dated from the fourth century [7, p74]) of the use of the horseshoe arch prior to the Islamic era, most researchers believe that it was in Islamic Spain that this arch type was fully developed and used.

***Pointed arch*:** (Fig.2-i1) An arch whose intrados is composed of two intersecting arcs, with each a part of a circle. Each of the two radii of these circles is bigger than half the distance between their centers.

It seams that slightly pointed vaults had been used in the drains of Sargon's palace in Khorsabad (722-750 BC) in Mesopotamia and in Egypt [5, p78]. Also there are a few examples for the use of the pointed arch in elevations during the pre-Islamic times (like in Qasr Ibn Wardan -about 50 miles north-east of Homs- built between 561-564), but its development and extensive use was during the Umayyad architecture in examples like Qusayr 'Amra (712-15) and Hammam as-Sarakh (725-30) and many other examples [7, p102-103]. On the other hand, its full use as the basic unit for a system of construction in ribbed vaults was not realized until the Gothic period.

***Two-centered arch*:** (Fig.2-j1) An arch whose intrados is composed of four parts: Two arcs flanking two lines each of which is tangent to one of the two arcs. It is similar in concept to the pointed arch. One difference is that in the pointed arch the intrados is the intersection part between its two circles, while in the two-centered arch the outer profile of the two circles is joined with two tangent lines drawn according to a point located on the vertical center line of the arch (this same point is the joint direction for the stones of inclined lines). Another difference is that there is no need for the radii of the circles of the two-centered arch to be bigger than half the distance between their centers, as in the pointed arch. Figure 3 shows these differences. The two-centered arch is also known as the Keel arch. It was an Islamic enhancement of the pointed arch [3, p. 279-280].

***Three-centered arch*:** (Fig.2-k1) An arch whose intrados is composed of three tangent arcs. Two of the arcs are similar to the 2-centered arch, while the third joins the first two and is a part of a circle whose center is located on the vertical center line of the arch (similar to the joint direction point in the 2-centered arch). The difference between the three centered and the elliptical arches is in the stone width. Where in the three centered arch it is constant, it is variable in the elliptical arch. This arch was used during the late Gothic period alone or as a part of a combination [8, pp. 199-200, and 9, p.47].

Four-centered arch: (Fig.2-l1) A sort of a pointed arch whose intrados is described form four centers, hence following the line of two pairs of tangent arcs for each side. Its first appearance was in Islamic architecture in "Baghdad Gate" in the town of Raqqa (772.). Later, it was frequently used by the Fatimid architects of Egypt [3, p.280, and 7, p.184-5, and p.321]. Nevertheless its most extensive use was in Iran in the Il-Khanid, and the Timorid periods [10, p. 68, and 11, p. 152].

Circular arch: (Fig.2-m1) An arch whose intrados is a full circle.

Other types: There are some other types of arches which were not included in this study. Some are combinations of the above (like the pointed-horseshoe and the pointed-segmental). These can be easily added at later stages because their parts are discussed here as will be seen later. Only two types are different: The ogee- and the multifol- arch (a geometrical and historical description of each can be found in many of the references of this paper).

4.2 Procedures applied to the types

The second step in creating the program was to analyze the types and find if there are any variations within each type. Two concepts of arch-alteration were found. Both produced new types within some of those presented earlier. They are the Florentine, and the rampant concepts. Following are descriptions of each.

4.2.1 The Florentine concept

The Florentine arch is an arch whose extrados is not concentric with its intrados and whose voussoirs are therefore longer at the crown than at the spring line. These arches were common in the region of Florence in the late Middle Ages and early Renaissance [12, p.217]. The shift of the two centers results in totally different visual effect for the arch. Moreover, the effect of a Florentine arch whose extrados center has a higher elevation than that of its intrados is totally different from the Florentine arch whose extrados center has a lower elevation than that of the intrados. Figures 2d2, and 2d3 display this concept for the round arch. The same concept was applied to the pointed arch and named as "Italian pointed" (Fig. 2i2). Historically this procedure was limited to these two types only.

4.2.2 The rampant concept

The rampant arch has one of its springers at a higher elevation than the other, making the arch form asymmetrical which is in contrast to the usual system (Figs. 2b4, and 2i4). It was very useful for the flying buttresses of the Gothic architecture as well as under the stairs (applied in the Islamic architecture as early as the ninth century [3, p. 285]). Another name for such an arch is the "raking arch" [12, p.455]. This procedure can be applied to many types of arches.

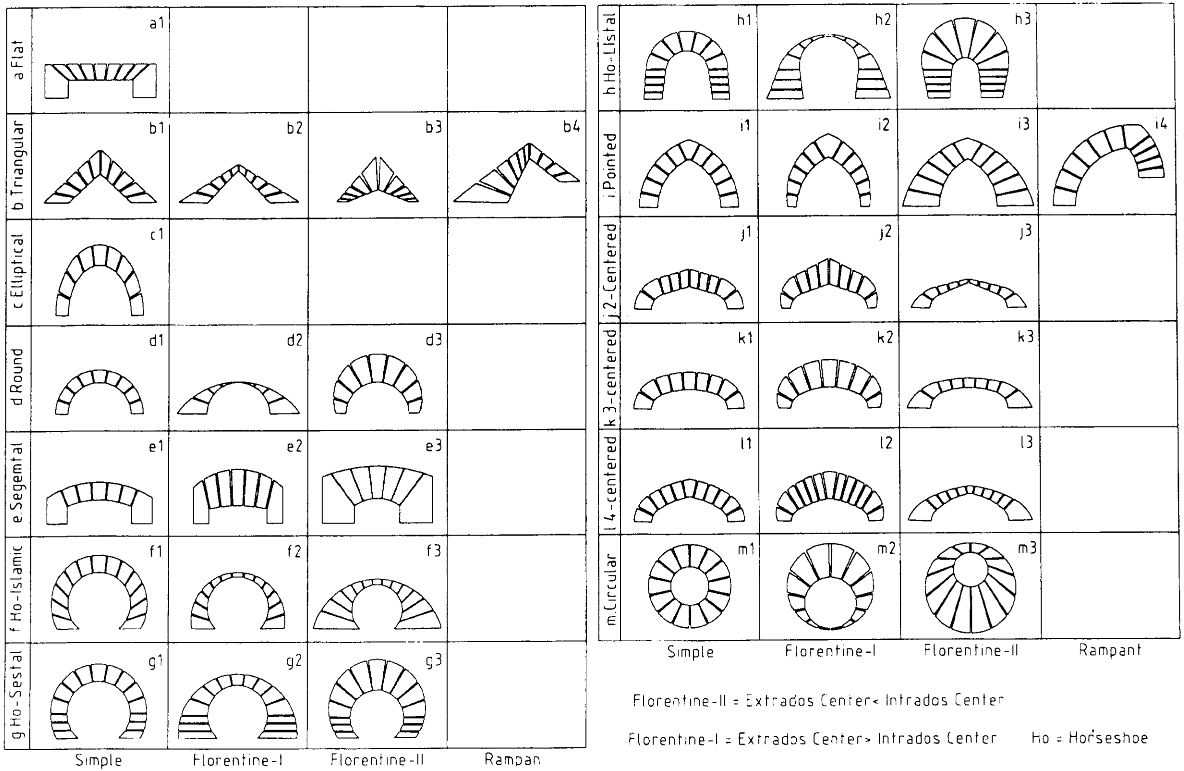

Fig. 2. The types used by the arch-creating software, and its variations, both the existing and the newly-proposed by this paper.
Florentine-II = Extrados Center <Intrados Center
Florentine-I = Extrados Center > Introdos Center
Ho = Horseshoe

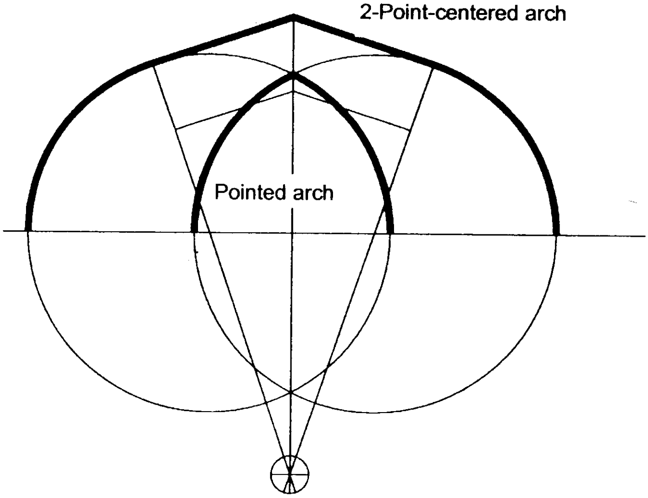

Fig. 3. The difference between the pointed and the two centered arch.

4-3 Analyzing the types into parts

The third step in creating the program was to find whether each of the specified types is a case of its own or it shares parts with other types. It was found that among all types only one (the elliptical arch) was a case of its own and that all the other types share parts. The parts shared are conceptual and not literal. There are three shared parts: One is common to seven types, one to three, and the third is common to two. There are some parts which were found to be singular. The total number of parts for all of the eleven types and their variations was found to be only eight. These parts and their relation to the types are shown in Fig.4. Each part was then described as a function defining its input and output data. Different concepts of parameterization were added to these functions so as to accommodate for the above, and some other procedures.

Following, each part will be presented as explained above.

4.3.1 Common parts

4.3.1.1 Part of a circle: (Figs. 5, 4-a, and 4-d)

By analyzing the pointed arch in comparison with the round arch, one can notice that the pointed arch is composed of three parts, two of which resemble parts of the round arch, while the third (the keystone) is a different one. From this observation we can think of the round arch as a special case of a more global shape that is a part of a circle with the starting and ending angles being variables. The round arch will then have its starting angle as 0.0-degrees and its ending angle as 180-degrees. On the other hand the two parts of the pointed arch of Fig.4aI will be the same global shape but with different values for their starting and ending angles. It is obvious from the same Figure that such a global shape will also describe a circular arch (with starting angle equal to 0.0-degrees and ending angle equal to 360-degrees), the segmental arch (with starting angle greater than 0.0-degrees and ending angle less than 180-degrees), and parts of the two- three- and four centered arches, as well as parts of two types of the horseshoe arch.

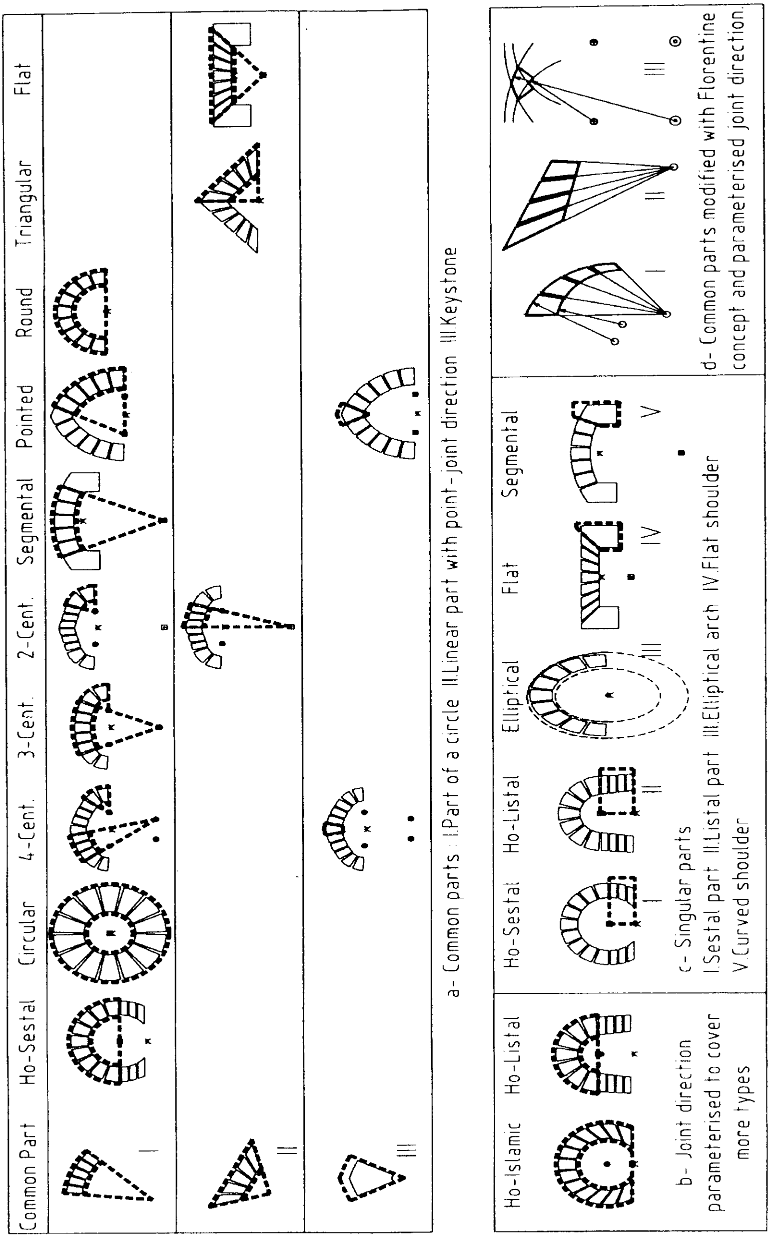

Fig. 4. The common and singular parts of the arch types.

4.3.1.1.1 The part-of-a-circle function description

The function must receive the following variables: The center point, the radii of both of the intrados and the extrados, the angle to start the arch with, as well as the angle to finish the arch with, and the joint distance.

It must calculate the points composing each voussoir, then pass the data to a function that would draw the stones.

4.3.1.1.2 Parameterizing the joint direction (Figs.5, 4b, and 4dI)

Considering the horseshoe arch - the Islamic family and the upper part of listal type - one notices that the above function (4-3-1-1-1) falls short of creating them. This is due to the fact that the joints of the stones are not directed towards the center of the arch, but to another point (on the base of the arch in case of Islamic horseshoe and above the center of the arch in case of the listal type).

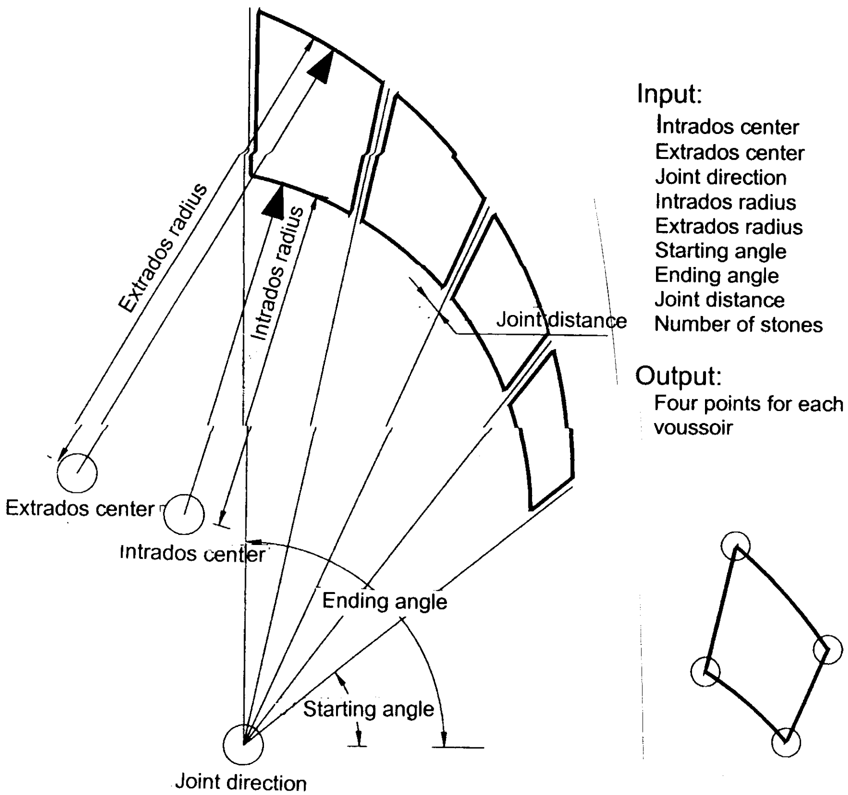

Fig. 5. Common parts I: Part of a circle.

To modify the previously discussed module (4-3-1-1-1) so that it would be able to create Islamic horseshoe arches, the variable set must also include the joint direction point.

To achieve the simple form of the arch the new variable (joint direction point) would coincide with the center point.

4.3.1.1.3 Applying the Florentine concept

To further modify the previously discussed module so that it would be able to create Florentine arches (Figs. 2-i2, and 2-i3), the variable set that it should receive must be as such: The center point of the extrados, the center point of the intrados, the joint direction point, the radii of both of the intrados and the extrados, the angle to start the arch with as well as the angle to finish the arch with, and the joint distance (Figs.4dI and 5). To achieve the simple arch, the two new variables, the center point of the extrados and the center point of the intrados, and the joint direction point must coincide.

4.3.1.1.4 More types

As mentioned earlier, the Florentine concept historically was only applied to the round and the pointed arch. This research has proposed to extend this concept to other tpes as well. By simply changing the values of the variables, we can create a triangular Florentine, two- three- and four- centered Florentine, horseshoe Florentine (with all of its variations). All of these represent new contributions made by this paper to the field of architecture (see Fig. 2).

4.3.1.2 Linear part of an arch with point-joint direction (Figs. 6 and 4aII)

Considering the flat arch, one notices that it is composed of three parts: two shoulders and a flat part. The last is composed of two horizontal lines which represent the intrados and the extrados of the arch, creating flat stones with joints directed to some point beneath. The triangular arch, on the other hand, is composed of two symmetrical parts. Each part is composed of two parallel lines which represent half of the intrados and the extrados of the arch, creating flat stones with joints directed to some point. Considering these two, one can easily conclude that the first (the flat arch's horizontal part) is a special case of the more general second case (one flat part of the triangular arch): a special case created when the two parallel lines are horizontal. Other similarities are the straight parts of the two-centered arch. Accordingly, all of these parts can be included in one single conceptual shape.

4.3.1.2.1 The linear-part function description

The function must receive the following variables: The inclination of the parallel lines, the vertical distance between them, the joint point, and the joint distance.

It must calculate the points composing each voussoir of the arch. Then it must pass the data to a function that would draw the stones.

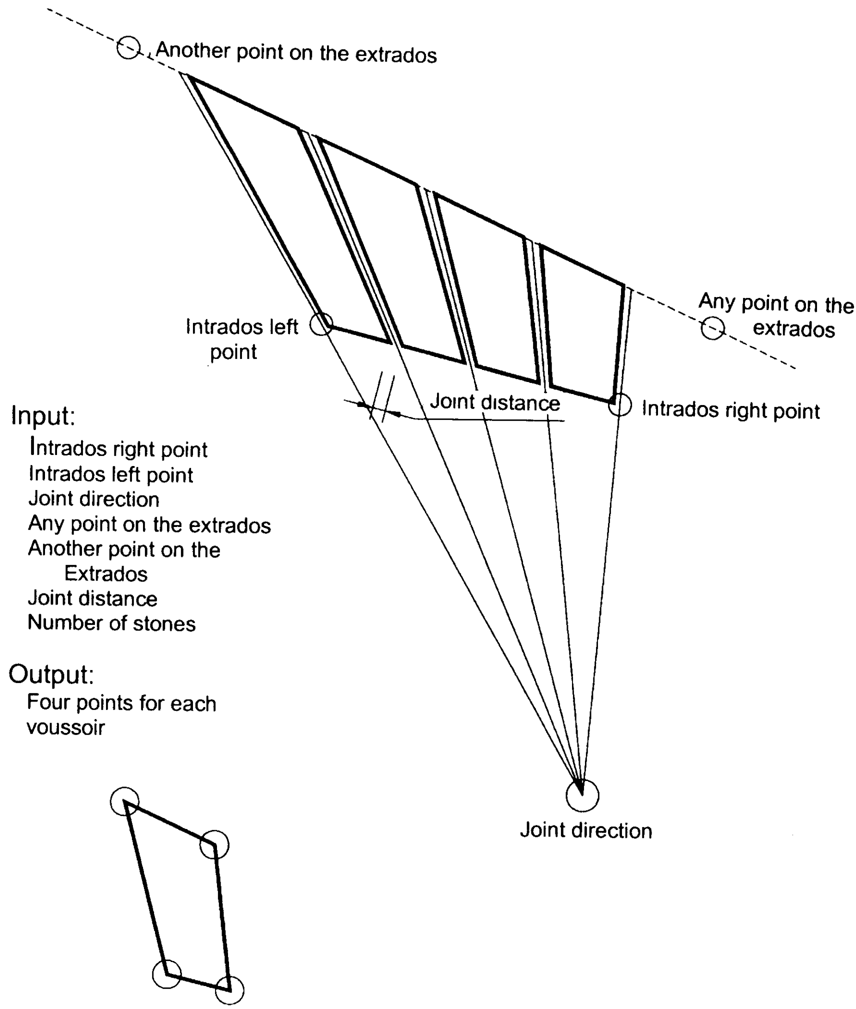

Fig. 6. Common parts II: Linear part with point-joint direction.

4.3.1.2.2 Applying the Florentine concept

Trying to extend the Florentine concept to this function means to allow the intrados line to be at a different angle than that of the extrados. This approach would lead to the Florentine triangular arch; another contribution of this paper (see Figs. 2b2, 2b3, and 4dII).

4.3.1.3 The keystone part (Figs. 7, and 4aIII)

Both of the pointed and the four-centered arches share similar keystones. It is a stone that is composed from the two arcs composing the intrados and the other two composing the extrados. It must define the intersections of these arcs and draw the stone according to these as well as the joint direction and the locations of the centers.

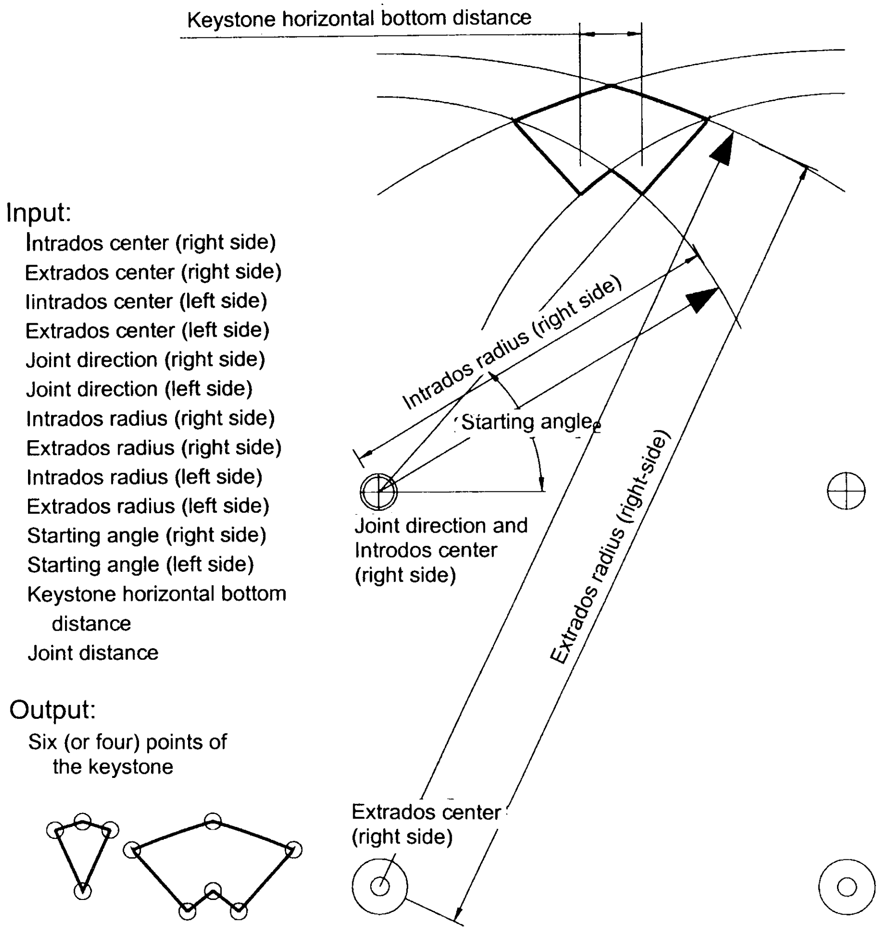

Fig. 7. Common parts III: Keystone.

4.3.1.3.1 The keystone function description

The function must receive the center of the intrados, the radii of the intrados and the extrados, and number of stones for both sides of the arch, as well as the joint direction, and the horizontal width of the stone. It must then calculate the six major points (or in some cases four points- see the Figure) of the keystone, then pass it to a function that will draw it according to the desired curvature of the stones.

4.3.1.3.2 Applying the Florentine concept

To apply the Florentine concept for this part so that it will coincide with the previous modules, the center of the extrados must be added to its input list (Figs. 7, and 4dIII).

4.3.2 Special (singular) parts

Following is a brief description of the singular parts, each of which is limited to an individual type. Each one was modified so as to accommodate the Florentine concept and parameterize the joint direction in the same manner explained for the common parts above.

4.3.2.1 The elliptical arch (Figs.8, and 4cIII)

The function must receive the center of the arch (which is the mid point of the line joining the springers), the intrados and extrados horizontal radii, the Y-factor related to the X-distance, the joint distance, and the number of stones.

It would output four points for each of the arch voussoirs, and pass it to a function that will draw them.

This is the only type with no Florentine option. The reason is that the voussoirs are not uniform in thickness in the first place.

4.3.2.2 The sestal part (Figs.9, and 4cI)

The word sestal is provided by this paper and, as indicated above, it means "SEctorial Stones Directed towards a Line." (Fig.2-g1). The function calculates the points of the voussoirs of the lower part of the sestal horseshoe arch. Its variables were parameterized so as to accommodate the Florentine concept. The input to the function are the intrados and the extrados centers and radii, the joint direction and number of stones. The output is the four points for each voussoir of the lower part of the arch.

4.3.2.3 The listal part (Figs. 10, and 4cII)

The word listal is provided by this paper and, as indicated above, it means "LInear Stones Directed Towards a Line". The function calculates the points of the voussoirs of the lower part of the listal horseshoe arch. Its variables were parameterized so as to accommodate for the Florentine concept. The input to the function are the intrados and the extrados centers, the arch center, the horizontal distance of the intrados from the arch center, the horizontal distance of the extrados from the arch center, the angle of the intrados line, the angle of the extrados line, the joint direction and number of stones. The output is the four points for each voussoir of the lower part of the arch.

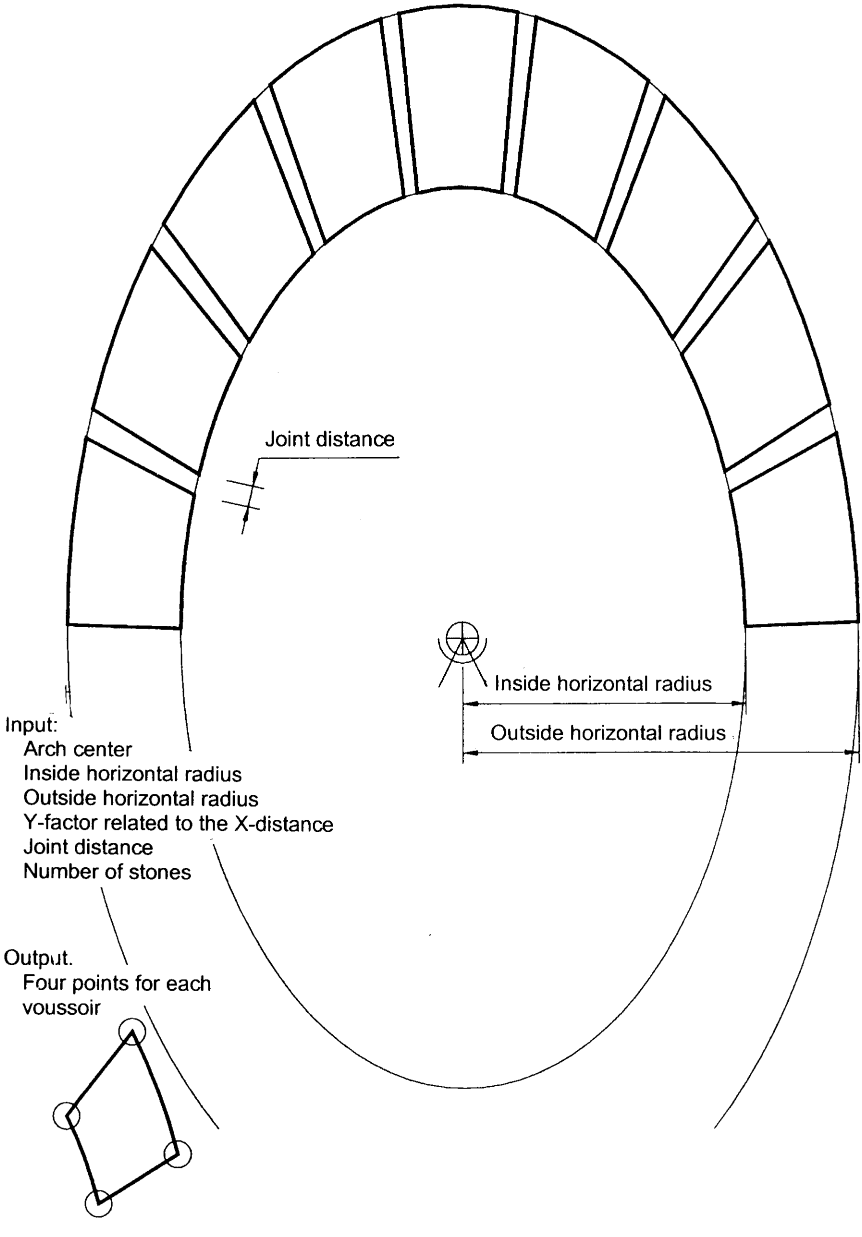

Fig. 8. Singular parts 1: Elliptical arch.

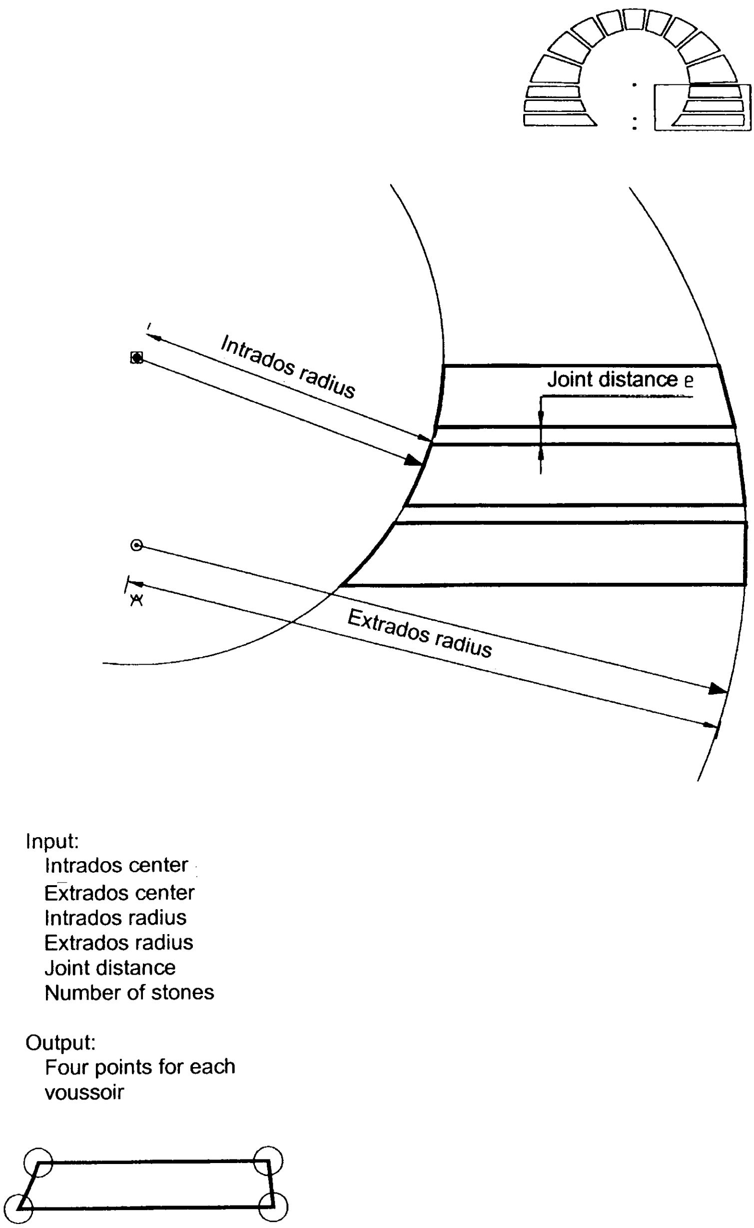

Fig. 9. Singular parts II: Sestal (Sectoral Stones directed Towards A Line).

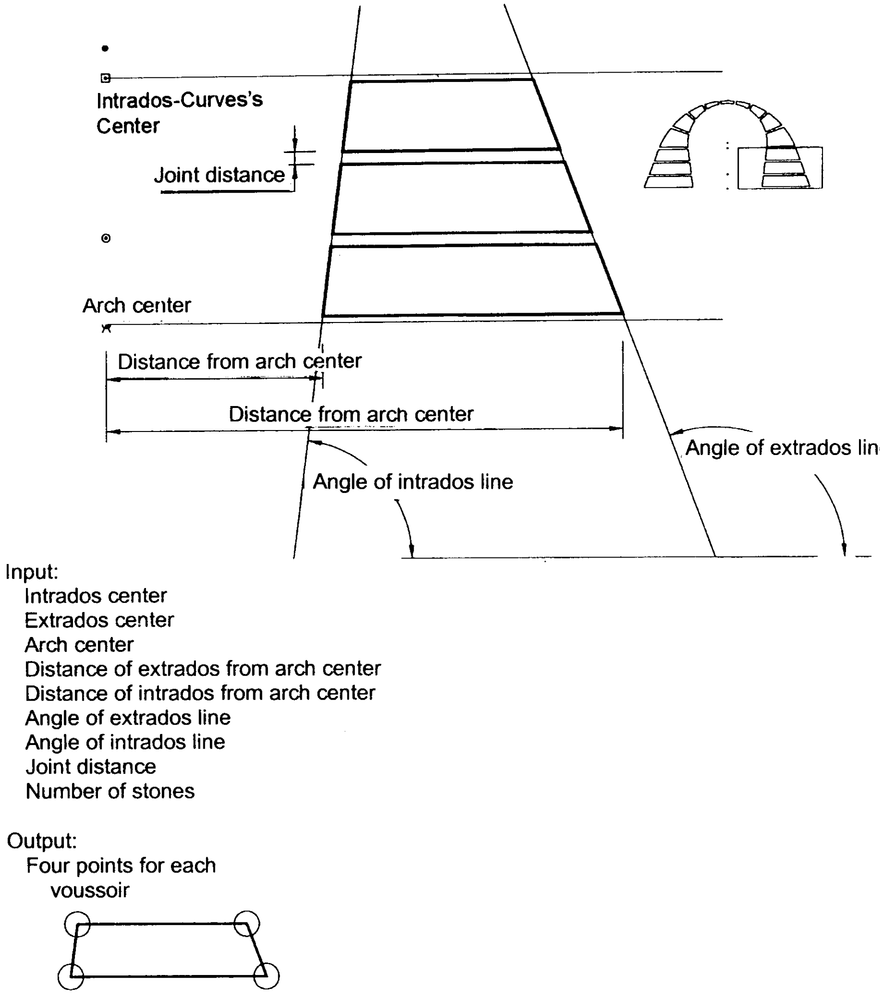

Fig. 10. Singular parts III: Listal (LInear Stones directed Towards a Line).

4.3.2.4 The linear shoulder part (Figs. 11, and 4cIV)

This is the shoulder of the horizontal flat arch. The input to the function will be the intrados mid point, the joint direction, half the length of the arch, its width, the shoulder height from the inside, and the shoulder width. The output will be five (in some cases four, see Fig. 11) points describing the shoulder stone. The Florentine concept does not apply to the flat arch.

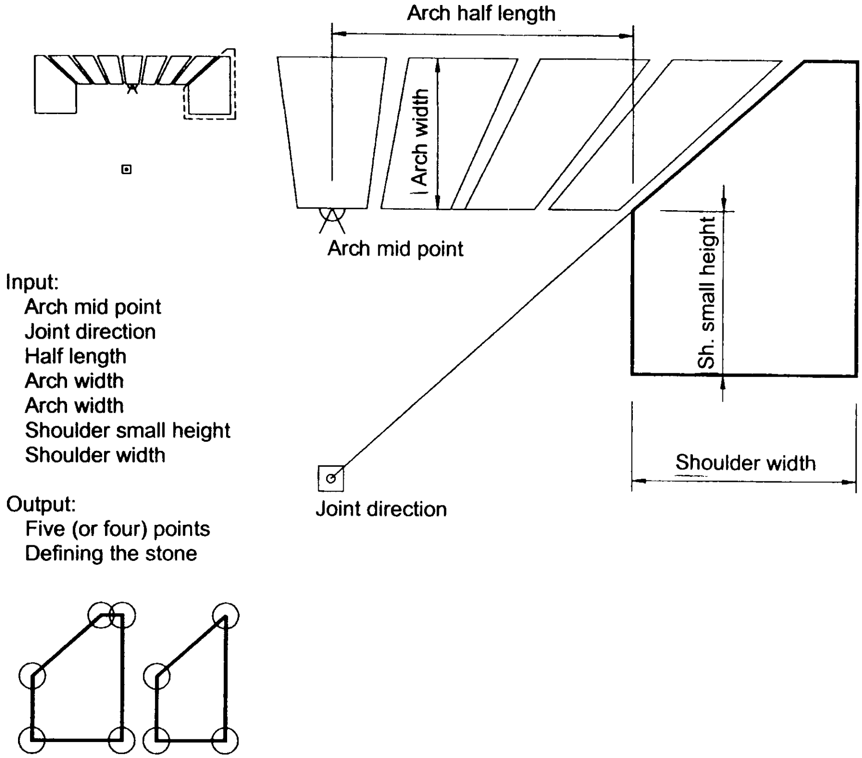

Fig. 11. Singular parts IV: Flat shoulder.

4.3.2.5 The circular shoulder part (Figs. 12, and 4cV)

This is the shoulder of the segmental arch. It can be one of three shapes depending on the shape of its upper line: either a curve (continuing that of the extrados), a straight line (similar to the linear shoulder), or being without one (see Fig.12). The input to the function will be the arch mid point, the intrados and extrados centers and radii, the joint direction, the shoulder inside height, and the type of the shoulder (whether linear or flat). The output will be five (or four) points describing the shoulder stone.

4.4 Applying the rampant concept

To apply this concept on the arch design, no modifications to the functions described above are needed; but in each arch where this concept is applicable (i.e. the pointed and the triangular arches with their variations), the arch would not have a single set of variables that is applied to its two sides. Instead there would be two sets of variables, one for each side (see Figs. 2-b4, and 2-i4).

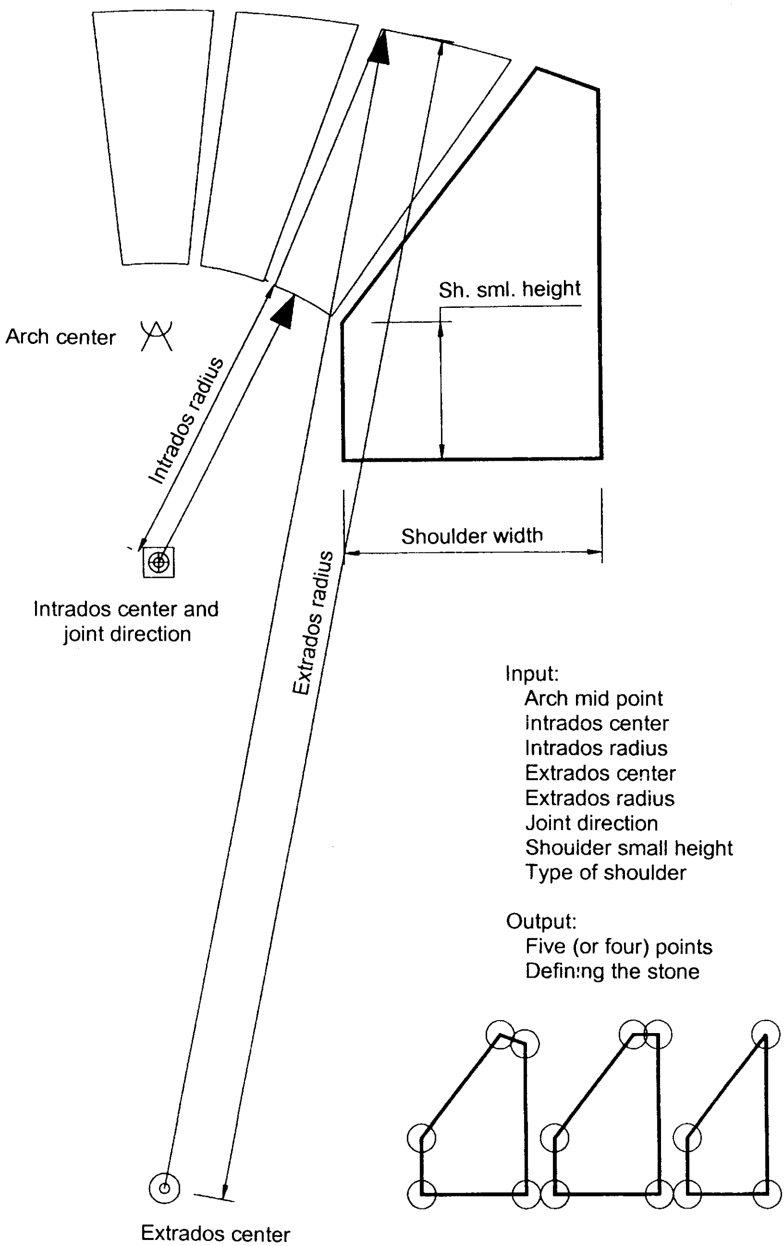

Fig. 12. Singular parts V: Segmental shoulder.

4.5 General variables of an arch

Besides the special variables of each type and sub-type of arches, there are some variables that are common to all. The final step of program design was to determine these. They are:

Number of stones: The most obvious variable of all. The effect it gives the arch can vary form unity (when it is equal to one) to extreme fragmentation.

Joint distance: Although the joint distance for a usual arch varies from 1 to 2 cm, this variable can be used for modern decorative arches where it can be enlarged to exceed the width of the stones, giving different effects and feelings.

The relation between the intrados and the extrados (or stone width) : A very important variable that affects the stability and the load-transfer-capability of an arch.

An example of how each of these variables can affect the final output can be seen in Fig. 13. There, the simplest round arch was taken as an example and in each case only one variable was altered and the other two fixed. As can be seen, there is no limit for the number of permutations. The possibilities increase further for a more complex type (like four centered arch).

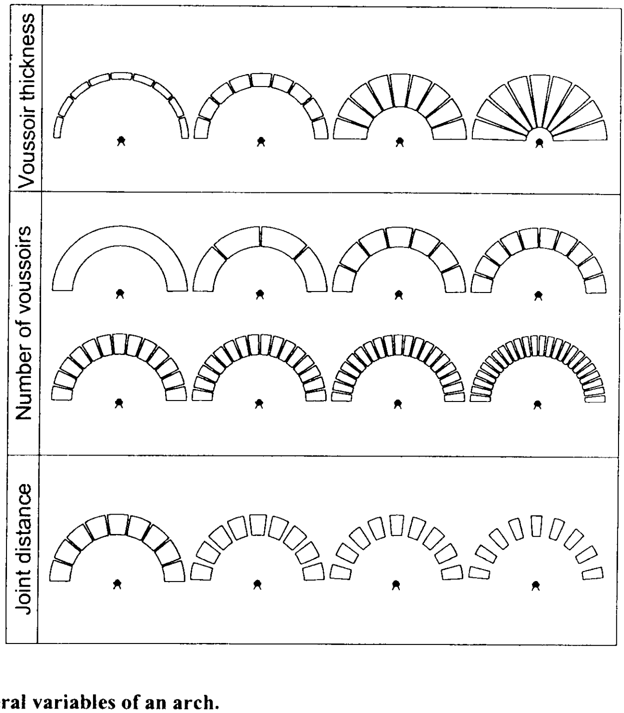

Fig. 13. General variables of an arch.

5. Module Design

There are three major types of modules in this program (shown in Fig. 14). They are:

Data collecting modules: For each type of arch there is a separate function that collects the relevant data of that type. Then it will call the appropriate calculating module(s), explained in section 4-3, as shown in Fig. 14. For example, the round arch data-collecting function will start by asking for the location of the arch in the drawing, then it will ask whether the arch is simple or Florentine, and accordingly it will ask for the location of the center of the intrados (and that of the extrados in case of the Florentine), and then the number of stones. It will then pass data to the "part of a circle" function that will produce the points for each voussoir, and then pass the output to its drawing function. These modules are: FLAT, the data collection module for the flat arch (Fig. 15); TRI, the data collection module for the triangular arch (Fig. 16); ELLIP, the data collection module for the elliptical arch (Fig. 17); ROUND, the data collection module for the round arch (Fig. 18); SEG, the data collection module for the segmental arch (Fig. 19); HORSH, the data collection module for the horseshoe arch (Fig. 20); POINTED, the data collection module for the pointed arch (Fig. 21); 2CEN, the data collection module for the two centered arch (Fig. 22); 3CEN, the data collection module for the three centered arch (Fig. 23); 4CEN, the data collection module for the four centered arch (Fig. 24); and CIRC, the data collection module for the circular arch (Fig. 25).

Calculating modules: The calculations are done by the common and special functions described above in section 4-3 and shown in Figs. 5-12. The data obtained is then passed to the drawing modules. These modules can be thought of as the basic engine of the whole program and some can be used for many types.

Drawing modules: The modules which actually draw the arches. They correspond to the modules of the previous section and not to each arch type separately.

Special modules: The modules which handle the environment of the program and its variables (local and global), and the program storage functions ...etc. Within each of the above modules there are local variables that hold data for any specific arch. In addition, there are some global variables that are constant for the whole program or at least for one session of it. These variables are the joint distance and joint location (whether the joint distance is located on the intrados, the extrados, or a point on the middle), and a variable that contains the meaning of a unit whether a millimeter, a centimeter, a meter, or other.

Figure 14 shows the structure of the whole engine of the program with the above modules indicated.

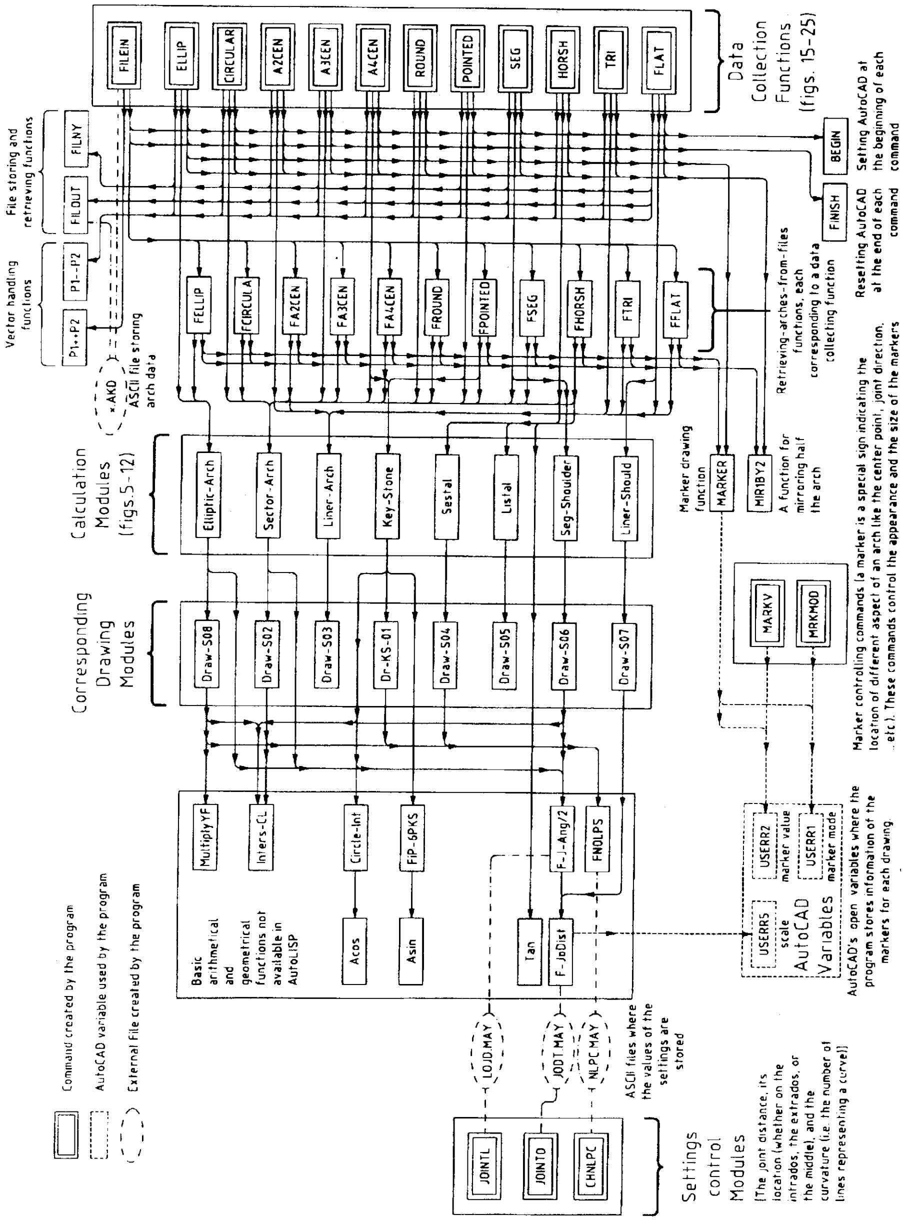

Fig. 14. The engine of the arch-creating software.

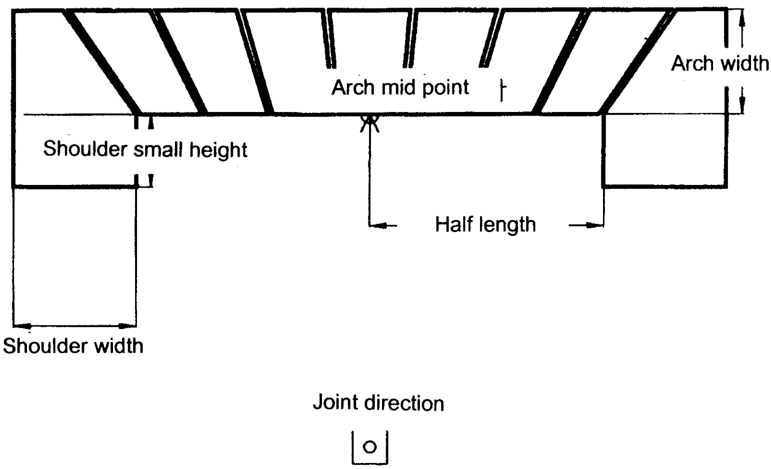

Fig. 15. Data collected by the flat arch module "FLAT".

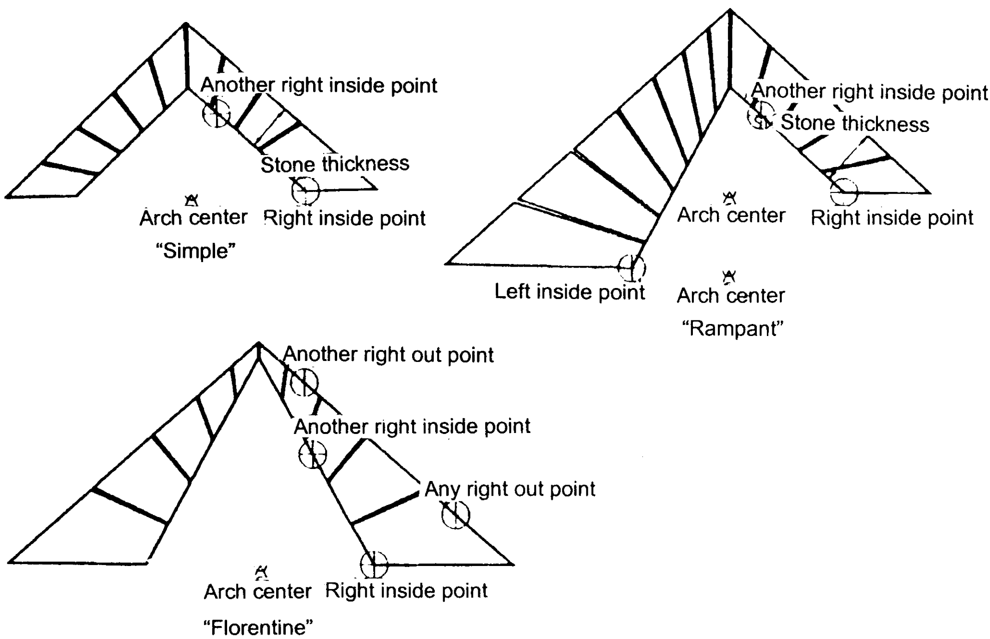

Fig. 16. Data collected by the triangular arch module "TRI".

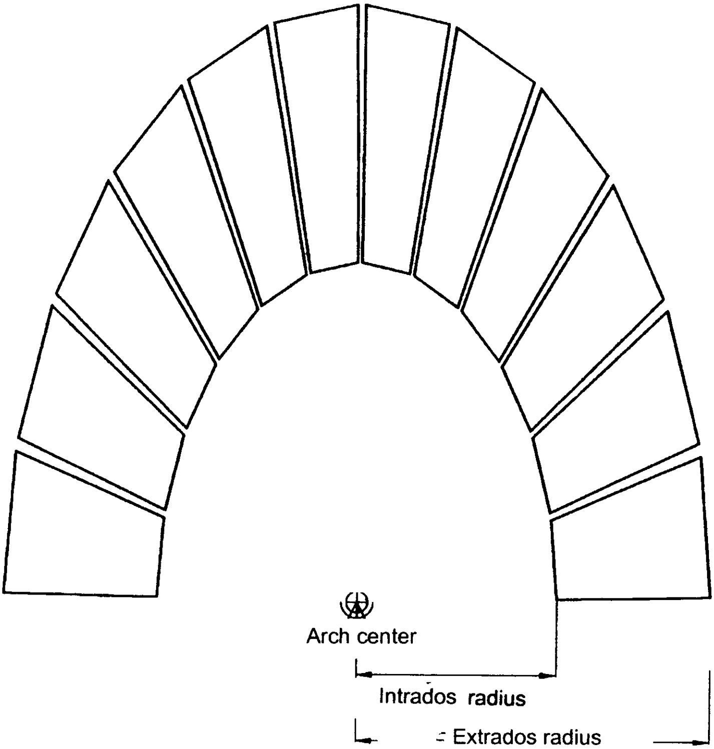

Fig. 17. Data collected by the Elliptical arch module "ELLIP".

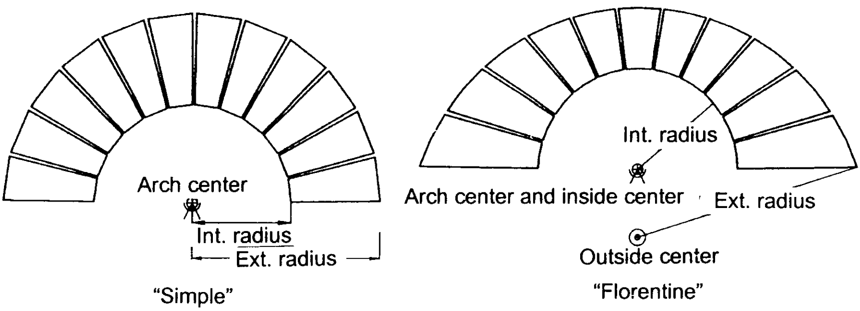

Fig. 18. Data collected by the round arch module "ROUND".

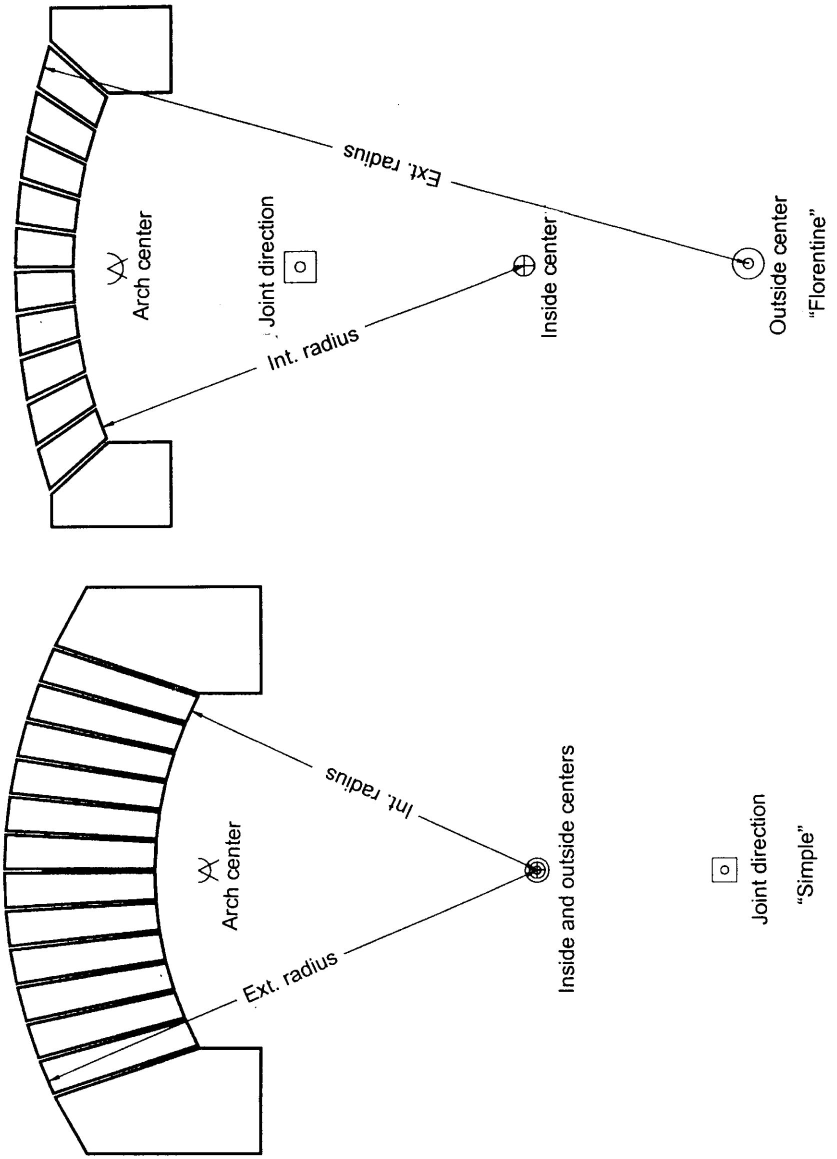

Fig. 19. Data collected by the segmental arch module "SEG".

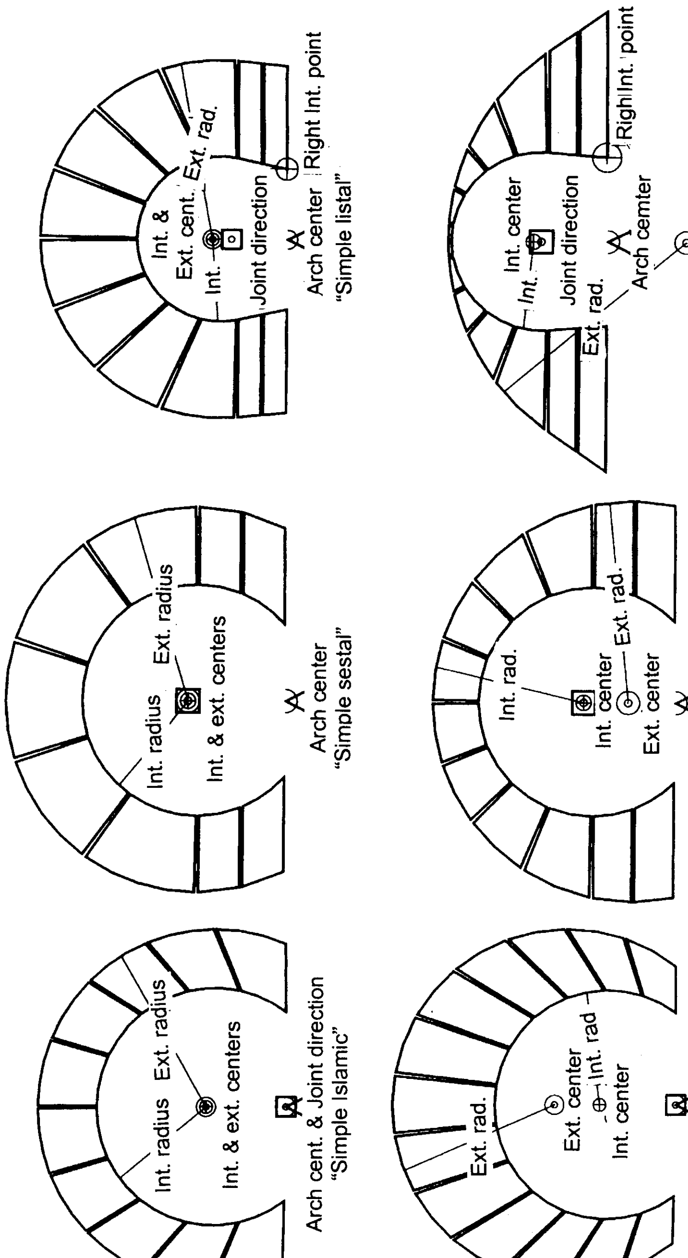

Fig. 20. Data collected by the horseshoe arch module "HORSH".

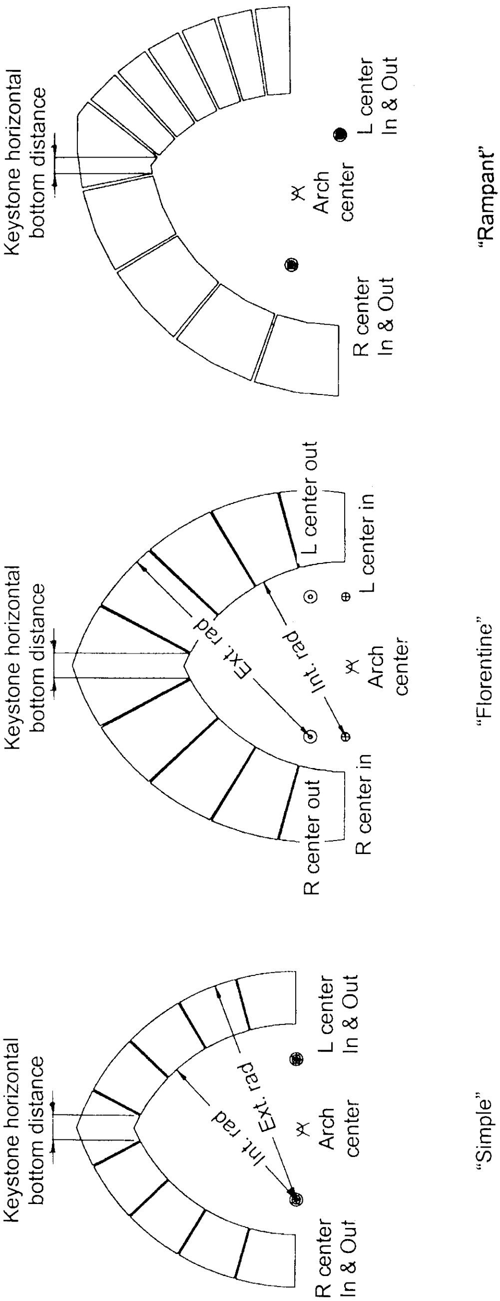

Fig. 21. Data collected by the pointed arch arch module "POINTED".

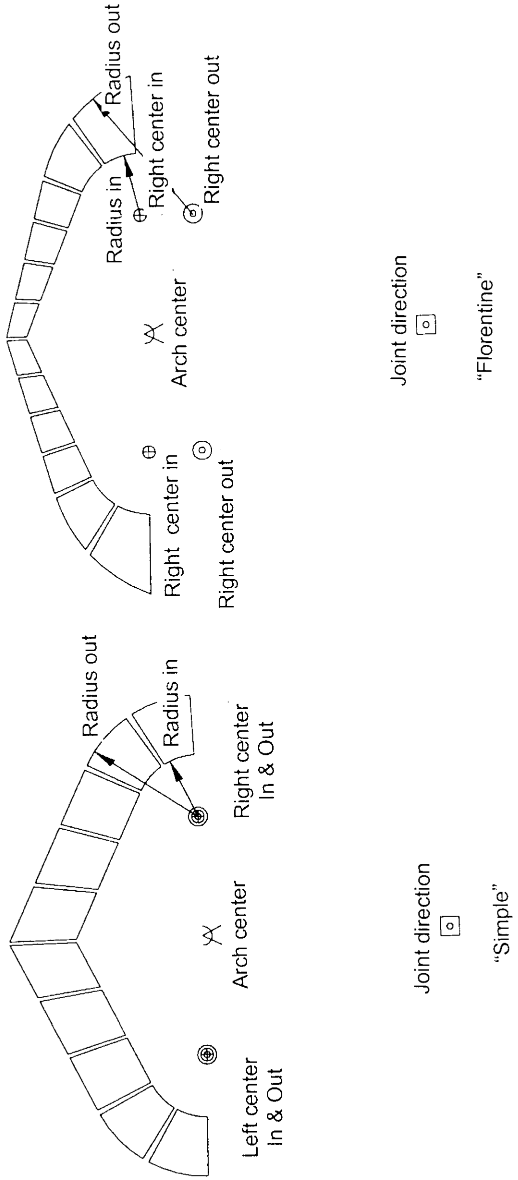

Fig. 22. Data collected by the two-centered arch module "2CEN".

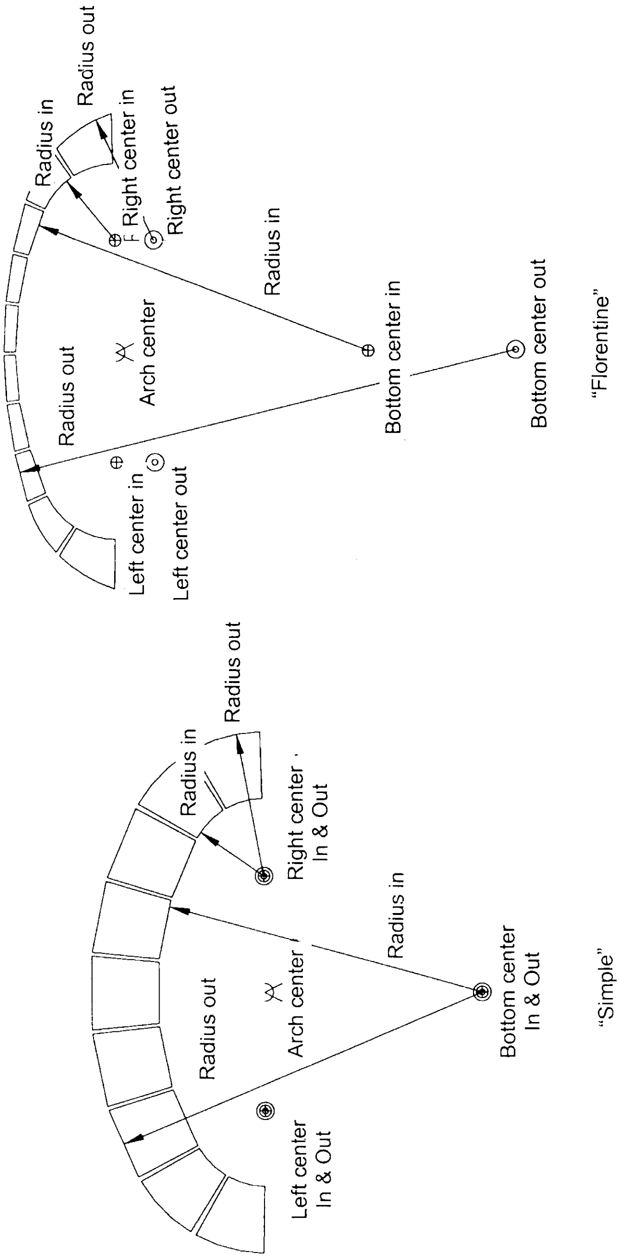

Fig. 23. Data collected by the three-centered arch module "3CEN".

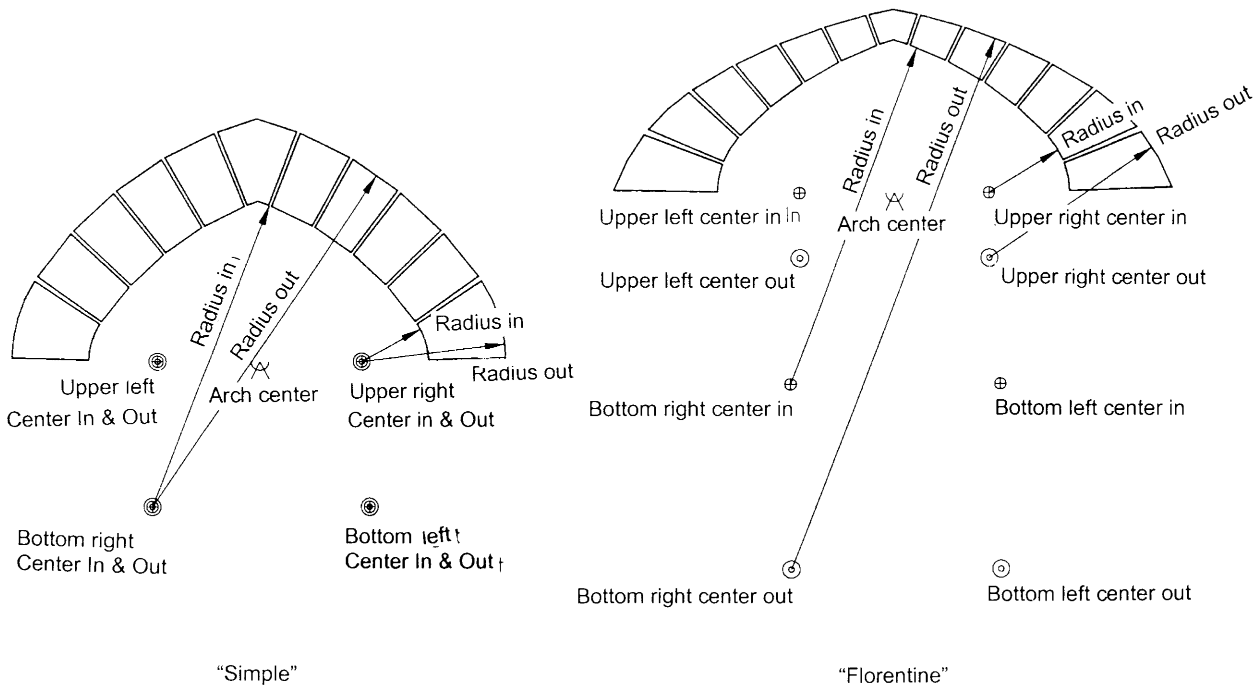

Fig. 24. Data collected by the four-centered arch module "4CEN".

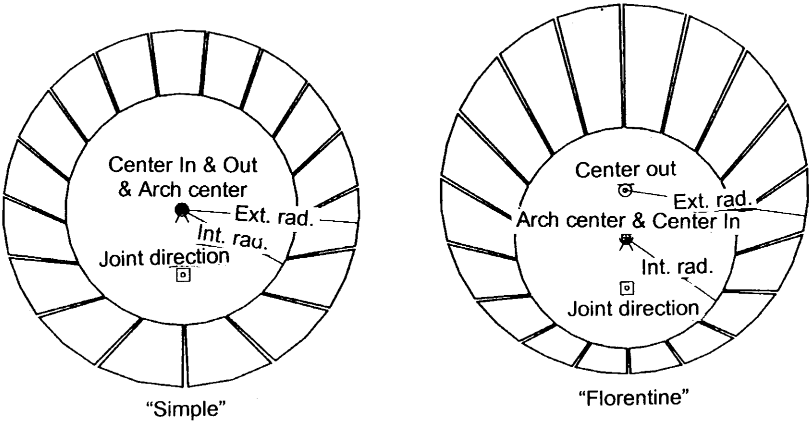

Fig. 25. Data collected by the circular arch module "CIRC".

6. Platform and Language

Usually an arch is not a single architectural drawing. Instead it constitutes a part of an elevation drawing. To create a program that only draws arches will cause a lot of confusion to the user who needs to complete the whole drawing, not only a part. To provide some drawing facilities along with the program will not be sufficient and the more complex the capabilities added, the greater is the burden on the original program. Accordingly, there is a need for an environment that provides capabilities to draw the other necessary parts and allow for the arch-creating program to work in a compatible manner, within its constrains. Upon investigating, the AutoCAD environment was found to be most appropriate. First, it is the most widely used program among architects [13]. Second, it provides the user with very powerful drawing capabilities. And finally, it has an open architecture where users and AutoCAD developers can write their own programs using a resident programming language called Auto LISP. Auto LISP is a high level language that is well suited to graphic applications. It is a special dialect of the LISP language. For a detailed discussion of AutoCAD and Auto LISP refer to [14] and relevant manuals of Auto CAD.

Therefore, a program was written and tested in Auto LISP. All the arch-drawings of this paper were produced using this program[2].

[2] The program was tested on a legal copy of AutoCAD 14 owned by the author (reg. No. 647-00073171). To obtain a copy of the arch-creating software please contact the author on myagham@hotmail.com myagham@ksu.edu.sa or the department address.

7. Interface

The basic interface of AutoCAD software is a group of commands that can l typed on a command-line, or picked from a screen menu, a pop-down menu, or a tabl menu. After the command has been initiated, a series of questions are asked, and tl response to them can be a mixture of the four previous methods.

Input to the program: In accordance with the AutoCAD system, each major tyı listed above was made as a separate command with the sub-types as options withi Screen-, pop-down- , and tablet- menus were prepared for all arch-types. Thus, the ar commands can be approached from the command line or any of the different menus.

Output: The outputs of the program are AutoCAD objects. They can be access and modified as such. Once the command sequence (which represents one arch-typ ends, the program gives control back to AutoCAD.

Storage needs: In many cases the architect needs to use arches of different scal but with the same proportions. This program allows for the storing and retrieval arches designed as ASCII files. Each time the user wants to retrieve an arch, it will t calculated and redrawn again (the same way they were drawn the first time but witho interaction with the user) according to the current joint distance and location. Th mechanism is necessary and cannot be accomplished by the AutoCAD's scale comman The pure scaling of an arch will cause every aspect of the arch to scale in a proportion manner. Thus, if the original joint distance was 1.5 cm. for an arch with a span of meter, then it will become 7.5 cm. when the arch is scaled five times (increasing tl span to 5 meters). Surely, such an effect is not desired. The ASCII storage capabili allows the user to recall any saved arch and fit it within the drawing according to tl current joint distance determined by the user.

8. A Sample Run of the Program

Figure 26 shows a sample run of one of the program commands, the pointe command. The command sequence presented in the Figure is the sequence which wi appear when using the standard "command line" of the AutoCAD. If other types menus were used some alterations might be found. The time needed for the creation this sample is less than one minute. The user can enter his data by typing or by pickin on the screen. He can enter any value even if he does not understand the meaning of th prompt, because the program will check the validity of the data and ask fc modifications when necessary.

As seen in Fig. 26 the sequence of the prompts is very similar to that of the normal AutoCAD command. The arch command actually acts as a resident AutoCAD command. Figure 27 shows how two arches created by the arch program are integrated in a drawing composed of other elements drawn using the AutoCAD program.

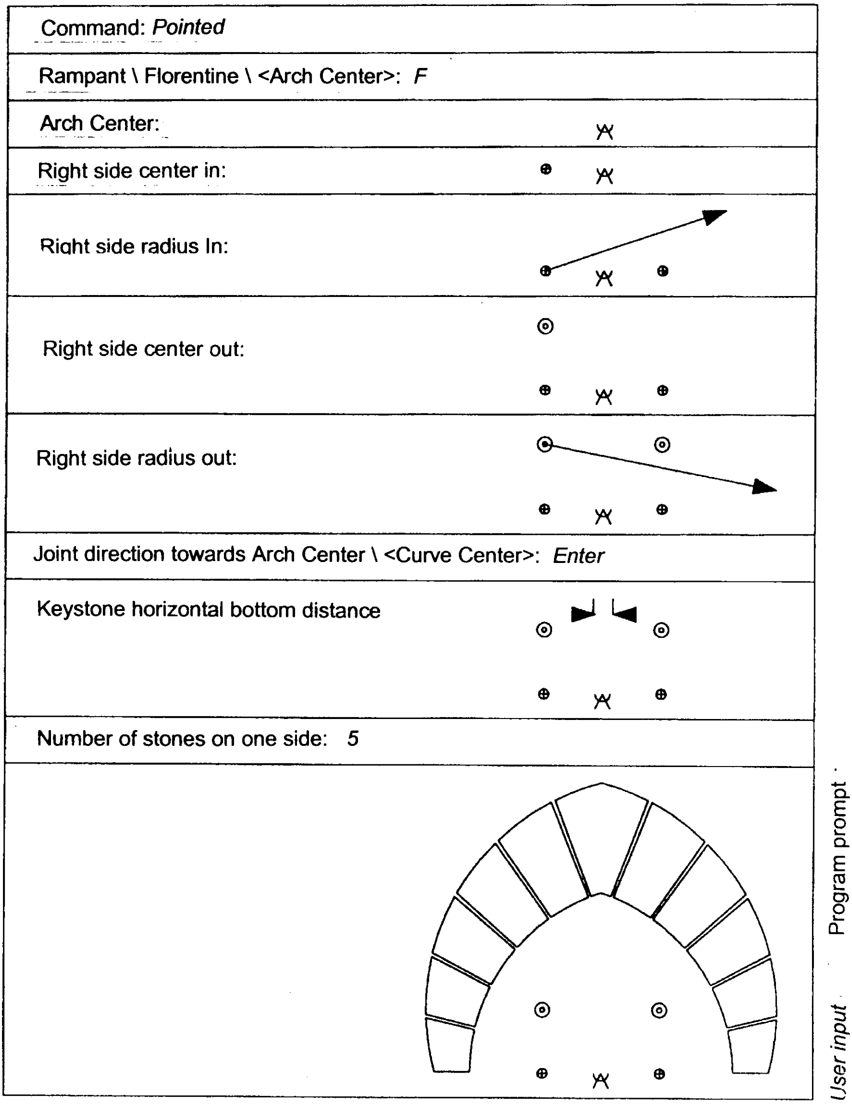

Fig. 26. Sample of the pointed command of the program (with the Florentine option).

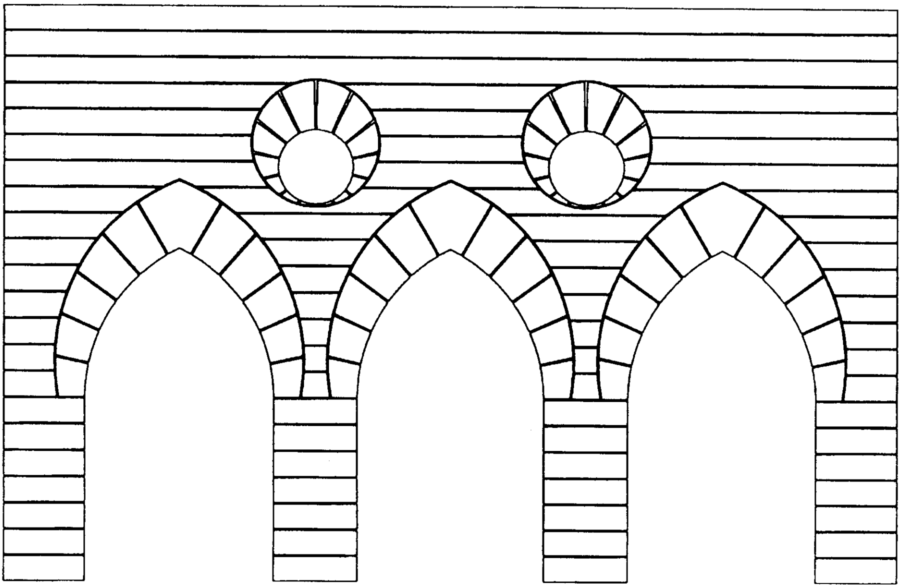

Fig. 27. Using other AutoCAD elements with archs of the program to create an architectural elevation. The arch command acts as a resident AutoCAD command.

9. Conclusion

Although the arch lost its constructional importance in architecture it is still a valuable element in the formal composition. This paper presented the foundations for an arch generation system and an application program. First, it defined the types of arches that it covered, and presented a short historical account for them. Second, it broke the arch types into parts, and defined the parts that are common to more than one type and those restricted to a single type. Thus the types were reduced into fewer parts. The paper also defined some procedures that had been used in history to create variations within one type, then it applied these procedures to other types creating totally new arch types that were never created before. Third, each part was declared as a computer function with its sets of input and output defined. Finally, it presented a computer program written for the creation of these arch types. The language of the program was chosen to be AutoLISP (the programming language of AutoCAD software). This choice was based on the nature of the arch which is not a final output in itself, but it is usually a part of an elevation, and AutoCAD provides the capability for producing all other elements without having them as a burden on the arch creating software if it was to be a stand alone package. A user's manual (from which some of the drawings of this paper were taken) was prepared, and the program can be easily used by professionals, educators and students.

A three-dimensional version of the porgram, to which more arch types can be added, will be the next step along the line of this research.

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برنامج لتصميم الأقواس

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ملخص البحث. يعد القوس (العقد) أحد عناصر التصميم المعماري، وتستغرق عملية تصميم القوس الكثير من الوقت (ما بين تصميم مبدئي، حسابات، رسم، تعديل، وإعداد رسومات نهائية).

يضع هذا البحث أساسيات برنامج حاسب لتصميم الأقواس، هذا البرنامج يقلل الوقت اللازم لتصميم القوس بشكل كبير، مما يرفع من مستوى التصميم العام حيث يوفر البدائل من خيارات واسعة من أنواع الأقواس للمصمم المعماري.

في البداية يعرف البحث أنواع الأقواس التي سوف يغطيها، ويحدد الأجزاء المشتركة ضمن مجموعات منها والأجزاء المفردة، ثم يطبق البحث الأفكار التحويلية التاريخية، التي استخدمت لإبداع أنواع جديدة، على الأنواع الحالية (هذا الأسلوب أدى بالبحث إلى إبداع أنواع جديدة من الأقواس لم تكن موجودة بالسابق كأحد إسهاماته في هذا المجال). بعدها يعرف البحث مجموعة المتغيرات لكل نوع ويناقش هندستها.

في المرحلة التالية يطرح البحث أفضل البيئات الحاسبية لتطبيق هذا البرنامج، فحيث إن القوس هو عنصر واحد ضمن العديد من عناصر التصميم المعماري فلابد من وجود بيئة حاسبية توفر القدرة على إنتاج كافة العناصر والأجزاء الأخرى، وتستوعب في الوقت نفسه برنامجا خارجيا (برنامج الأقواس). هذا أملي بيئة برنامج الـ AutoCAD والتي تسمح بالبرامج الخارجية (من خلال لغة الـ AutoLisp التي هي أحد لهجات لغة الـ LISP) كما تعطي المصمم قدرة عالية على إنتاج أي عنصر آخر.

أنتجت كافة الرسومات في البحث من خلال برنامج كتبه المؤلف بناء على النظرية المطروحة بالبحث وتلعب هذه الرسومات دور إثبات لتلك النظرية.