TECHNICAL UNIVERSITY OF GABROWO

Faculty of Mechanical and Precision Engineering

Eng. Ali Abdulkarim Gitan, MSc

OPTIMIZATION OF WORKPIECES LOCATION DURING MACHINING IN CAD ENVIRONMENT

AUTHOR's ABSTRACT

of a Dissertation

for acquiring the educational and scientific degree "Doctor"

Field of higher education: 5. Technical sciences

Professional field: 5.1 Mechanical engineering

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Gabrovo, 2025

The dissertation work was discussed and scheduled for official defence at a meeting of the Extended Department Council of the Department of Mechanical Engineering and Technologies at the Faculty of Mechanical Engineering and Instrumentation of the Technical University - Gabrovo, held on 16th May 2025.

The dissertation consists of 119 pages. The scientific content is presented in an introduction, 4 chapters and 3 appendices and includes 40 figures and 17 tables. 103 literary sources are cited. The numbering of the figures, tables and formulas in the abstract is in accordance with that in the dissertation.

The development of the dissertation was carried out in the Department of Mechanical Engineering and Technologies at the Faculty of Mechanical Engineering and Instrumentation of the Technical University - Gabrovo.

The official defence of the dissertation will take place on 18th September 2025 at 2:00 p.m. in the Conference Hall of the Technical University - Gabrovo.

Author: Ali Abdulkarim Gitan

Title: Optimization of workpiece location during mechanical processing in a CAD environment.

Number of copies: 3 pcs.

LIST OF ABBREVIATIONS USED

AD - automated design
DB - database
BE - base element
KB - knowledge base
MLTB - main location technological base
DG - double-guide location technological base
DS - double-support location technological base
ES - expert system
Cos - conical outer surface
Cis - conical inner surface
SE - structural element
LSM - layout solid models
G - guiding location technological base
S - supporting location technological base
SR - support-reinforcing location technological base
SC - support-centring location technological base
F - fixture
P - planar surface
Cyl os - cylindrical outer surface
Cyl is - cylindrical inner surface
SF - special fixture
BS - basing scheme
DBMS - database management system
TS - technical specifications
TSys - technological system
TrM - solid body model
LTB - location technological base
BSS - base surface shape
API - Automation Program Interface
CAD - Computer Aided Design
CAE - Computer Added Engineering
CAM - Computer Added Manufacturing
CAE - Computer Added / System Engineering
CAE - Computer Added / System Engineering

A. GENERAL CHARACTERISTICS OF THE DISSERTATION

Relevance of the problem

An important stage of the technological preparation of production is the design of the necessary fixtures for location, as well as the creation of design and technological documentation.

The development of engineering automation systems in recent years, especially in their CAM part, has necessitated the development of automated design systems in the field of technological preparation of production and, in particular, fixtures that include increasingly new tools, libraries, functional applications and levels of integration.

The use of CAD/CAE systems allows for the reduction of manual labour and the improvement of design quality, but does not allow for complex automation, since the key stages (selection of the optimal location scheme, calculation of fastening forces, selection of the design of the base elements) are performed manually. The individual stages of the design take a lot of time, which reduces the efficiency of their implementation.

Many of the existing automated design systems have specialized modules for developing technological equipment, but they mainly include the design of casting moulds, dies, and press-moulds, while the design of fixtures for locating the workpieces is carried out according to the design scheme for a simple product.

This approach is not rational, since the fixtures are specialized structures to which special requirements are placed during design.

One of the most complex and responsible tasks in the automated design of fixtures is the selection of an optimal scheme for setting up the workpieces. Therefore, it is necessary to supplement the CAD modules with specialized blocks for selecting optimal schemes for location of the workpieces, the development of which is of particular relevance when using integrated CAD systems that are well integrated with CAM modules of technological production.

Purpose and objectives of the dissertation

The purpose of the dissertation work is the development of a methodology and algorithms for selecting optimal schemes for location of workpieces during mechanical processing and their structural implementation using modern CAD systems based on the technology of three-dimensional solid body parametric modelling.

To achieve the set goal, the following ***main tasks*** have been solved:

1. Analysis and systematization of the schemes for establishment and development of criteria for the selection of basing elements, taking into account the conditions for geometric compatibility, allowing for the selection of a location scheme that satisfies the geometric shape of the workpiece.
2. Development of methodology and algorithms for ensuring the quality of fixture design based on the selection of an optimal location scheme and its constructive implementation.
3. Development of a model for automation of the design of an optimal scheme for location and its constructive implementation using modern CAD systems based on the technology of three-dimensional solid body parametric modelling.
4. Determining the structure of the software product and the necessary database for selecting an optimal identification scheme.
5. Development of a methodology for practical implementation of the automated system for selecting an optimal location scheme and a database with solid body models of BE.

Research methods

In developing the dissertation, the systems approach, object-oriented design and analysis, as well as fundamentals from the scientific specialties "Mechanical Engineering Technology" and "Automation of Engineering Work and Automated Design Systems" were used.

Scientific novelty

- Systematization of possible schemes for basing workpieces in fixtures for location in mechanical processing with a view to their use in automated design.
- The methodology and algorithm for selecting the optimal location scheme and its design and implementation depending on the required accuracy in processing and the required service life of the fixture.
- The defined criteria for: geometric compatibility, allowing the selection of a basing scheme that satisfies the geometric shape of the workpiece; selection of BE structures when using different technological bases.
- The developed methodology, models, algorithms and class and state diagrams that can be used to develop a software product for selecting an optimal location scheme.

Applicability

- The developed structural diagram of the software package necessary for selecting an optimal location scheme.
- The developed database with solid body models of base elements.
- Automated tables for: selection of models of base elements; preliminary assessment of the economic efficiency of the designed fixtures.

Approbation of the dissertation work

The dissertation work was reported and discussed at an extended meeting of the Department of Mechanical Engineering and Technologies at the Technical University of Gabrovo.

Stages of the dissertation work have been reported and discussed at:

- International Scientific Conference "UniTech 19", Gabrovo, 2019;
- 13th International Scientific and Practical Conference on Environment. Technology. Resources. ETR2023, Conference Proceedings, Rezekne, Latvia, 2021;
- National Conference on Mechanical Engineering and Machine Science. 08-10.09.2021, Varna (Mechanical Engineering and Machine Science Magazine 2021; Issue 31);
- National Conference on Mechanical Engineering and Machine Science. 08-10.09.2022, Varna (Mechanical Engineering and Machine Science Magazine 2022; Issue 32);
- Youth Scientific Forum "Science, Technology, Innovation, Business". 21-22.11.2024. Plovdiv.

Structure and scope of the dissertation

The dissertation work contains: introduction, table of contents, 4 chapters, classification of contributions, publications relating to the dissertation and references in a total volume of 119 pages including 40 figures, 17 tables and appendices of 44 pages, which include 16 figures and 2 tables. The list of used literary sources is composed of 103 titles.

B. SHORT SUMMARY OF THE DISSERTATION

CHAPTER ONE

METHODS FOR AUTOMATED DESIGN OF FIXTURES FOR LOCATION OF THE WORKPIECES IN MECHANICAL PROCESSING. PURPOSE AND OBJECTIVES OF THE DISSERTATION THESIS

The cycle of designing, manufacturing and implementing fixtures for the location of workpieces during mechanical processing takes up to 80% of the total time for technological preparation of a new production, and its costs reach 15-20% of the cost of the equipment. For this reason, the tasks related to improving quality, reducing the time for designing and manufacturing fixtures are one of the important problems of modern mechanical engineering production.

Solving the tasks set is achieved through: applying scientifically justified methodology; maximum use of standardized and normalized elements; use of computer technology.

A number of objective difficulties currently limit the automated design of fixtures. With the help of computer technology, individual design tasks, which is carried out in the traditional way, are solved.

To implement the tasks related to the design of fixtures, there are a number of methods, including automated design.

The phases and stages in the design of fixtures for location of workpieces are shown in Fig. 1.1.

From the literature review, it was found that the majority of works in the field of automation of fixture design are of a general nature, describing the general aspects of automated design. In this case, more attention is paid to the coding of the input information and the geometric analysis of the design object. In the works that consider the issues of automation in more detail, each stage of design is carried out locally, without complex automation of the design process.

As a result of an analysis of manual and automated design methods, the most suitable systems for designing the fixtures have been identified, providing modelling capabilities at minimal cost, such as Solid Edge v .6, Inverter, Solid Works etc. (Fig.1.3).

The shortcomings of the traditional (manual) method are revealed and the need for the use of an automated method for designing fixtures is justified.

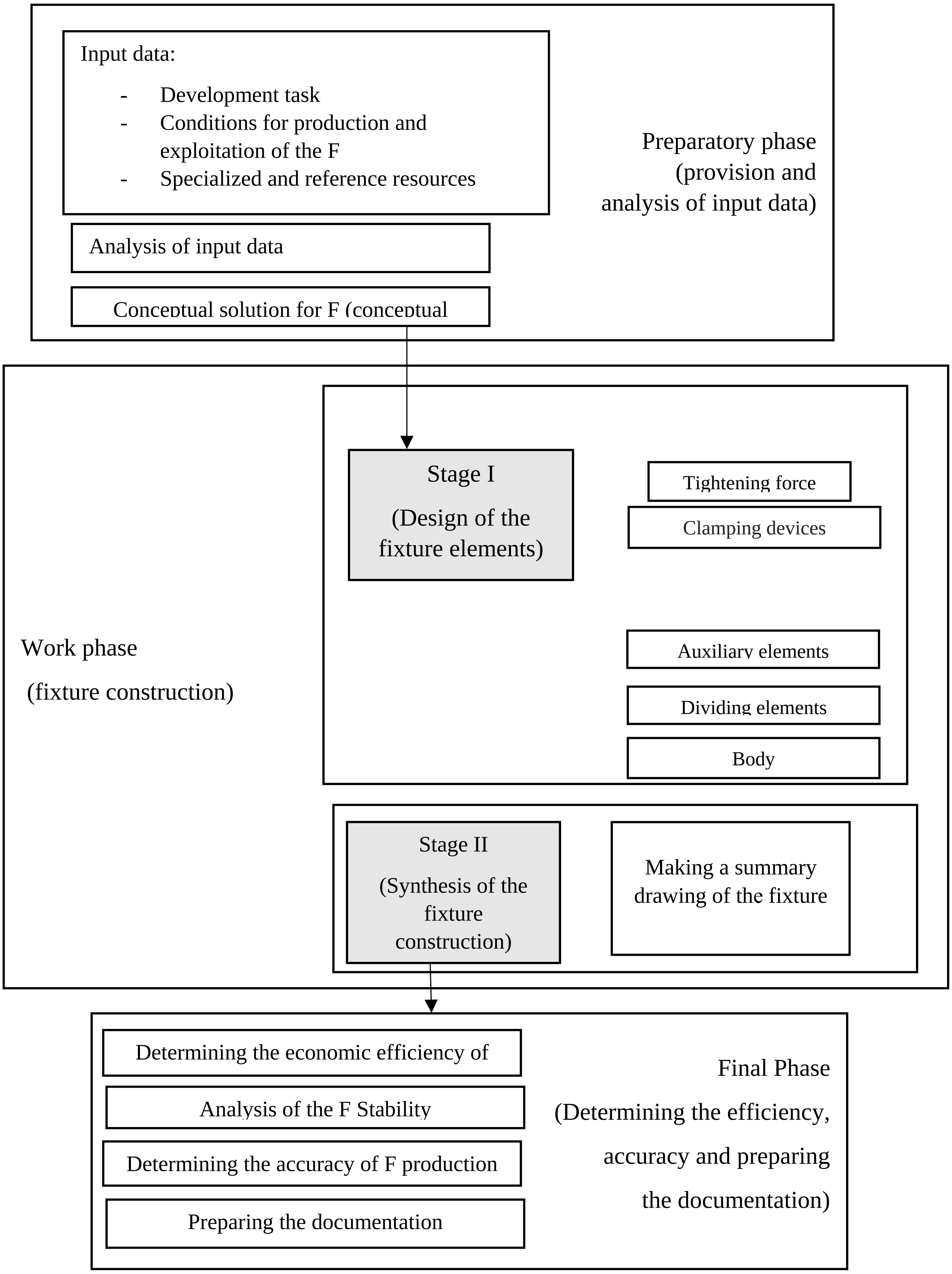


Fig 1.1 *Phases and stages in the construction of fixtures*

The task of automated design is complex and intricate, the solution of which requires significant research and systematization of the information used in the design, development of specific rules and methods for formalizing engineering solutions.

From the analysis of the stages in the design of fixtures, it has been established that ensuring their quality depends on the choice of an optimal location scheme (IS) for the workpiece and its structural implementation.

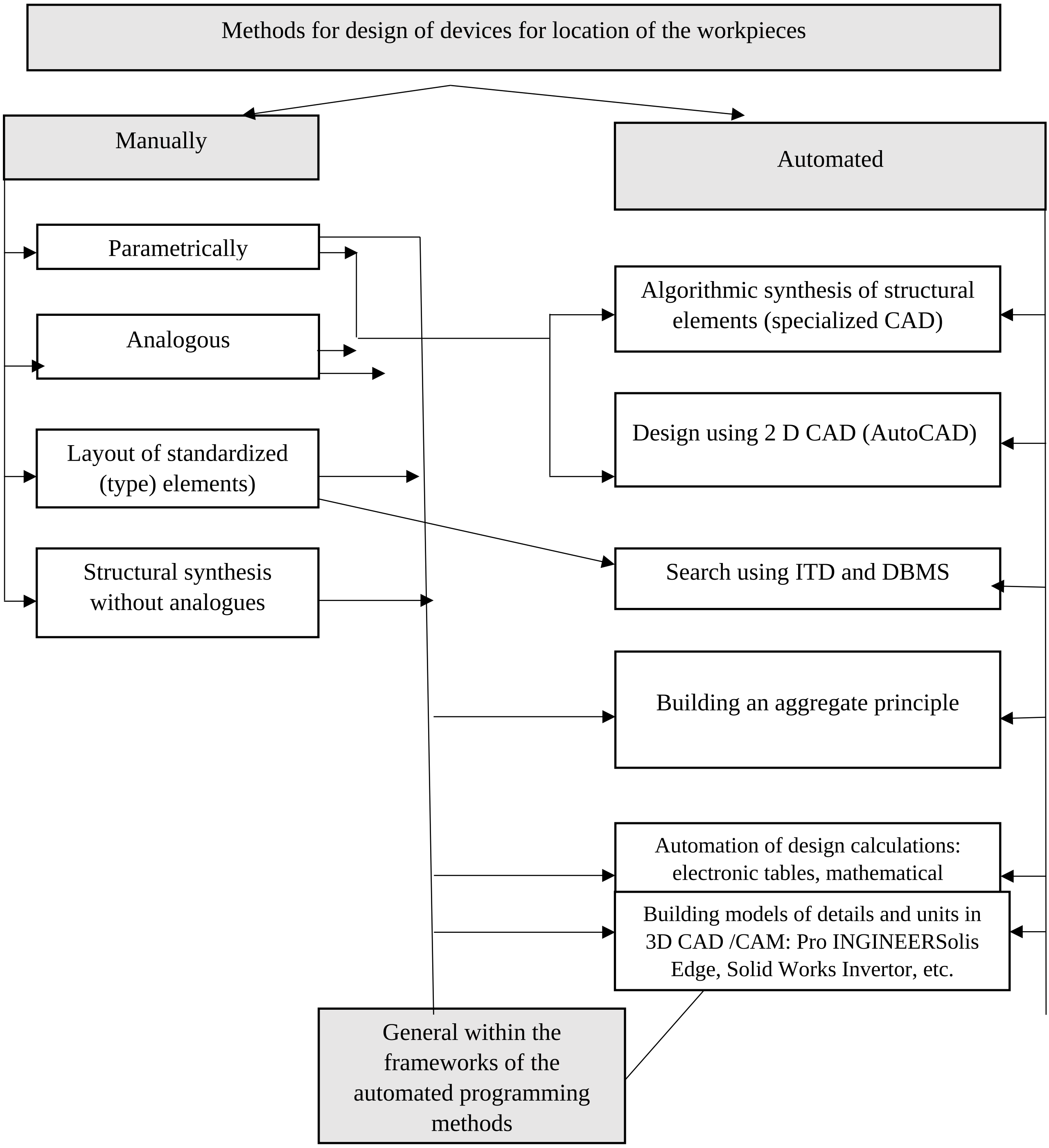


Fig. 1.3 *Methods for designing fixtures for the location of workpieces*

The most important functions performed by the fixtures are ensuring the necessary *accuracy of processing*, depending on the selected LS, and maintaining it over time - *the reliability of the fixture*, characterized by its period between repairs.

In this regard, the selection of an optimal IS and its structural implementation must be carried out according to the criteria of ***accuracy*** and ***reliability***.

The criterion for fulfilling the required *accuracy* is provided using the analysis of the inaccuracy of location of the workpiece and the tolerance of the corresponding technological size from the condition:

$$IT \geq \varepsilon_l + \omega, \quad (1)$$

$$IT \geq \sqrt{\varepsilon_b^2 + \varepsilon_f^2} + \varepsilon_{bw} + \varepsilon_w + \omega\ , \quad (2)$$

where IT is the tolerance of the executed size, μm; ε_L - inaccuracy of location of the workpiece in the F, μm ; ε_b - inaccuracy of basing, μm ;ε_f - inaccuracy of fastening, μm ; ε_{bw} - inaccuracy associated with the change in the shape of the contact surface of the base element (BE) during its wear, μm ; ε_w - inaccuracy from the progressive wear of BE, μm ; ω - average accuracy of the processing method, μm .

The other criterion influencing the choice of a IS, related to *reliability,* depends on ensuring the interval between repairs (IBR) set by the designer:

$$IBR \geq [IBR], \quad (3)$$

where [*IBR]* is the specified allowable interval between repairs of the fixture.

The analysis of the capabilities of modern CAD/CAE systems in choosing the optimal location scheme and its constructive implementation shows that their standard modules and tools can ensure the solution of the task of complex automation at this design stage, as well as provide a significant reduction in design time losses.

CHAPTER TWO

METHODOLOGY FOR SELECTING THE OPTIMAL SCHEME FOR INSTALLING THE WORKPIECES IN THE FIXTURES AND ITS CONSTRUCTIVE IMPLEMENTATION

A systematization of the possible basing schemes (BS) of the workpieces in the fixtures for location in mechanical processing has been carried out with a view to their use in automated design.

In the developed systematization of BS, several possible implementations correspond to one theoretical basing scheme, the number of which depends on the geometric shapes of the surfaces used for the location technological bases (LTB). Combining the possible LTB with the possible used BE (Table 2.2), the possible schemes of full basing are obtained (Table 2.4). The choice of BS for a specific operation (workpiece) depends on various factors. This systematization is significantly more rational, since its structure reflects the sequence of choosing the optimal BS - analysis of the theoretical BS, analysis of the geometry of the workpiece, formation of the possible list of BSs.

An approach is proposed for automated selection of a rational identification scheme based on the accuracy and reliability indicators (Fig. 2.2).

__Table 2.2__ Base elements

Basis elements	Designation	Basis elements	Designation
Support (cylindrical or flat)	S	Cylindrical mandrel cut	M_{cc}
Long prism	Pr_{l}	Conical mandrel	M_{con}
Long movable prism	Pr_{lm}	Long cylindrical bushing	B_{lc}
Short prism	Pr_{sh}	Short cylindrical bushing	B_{shc}
Short movable prism	Pr_{shm}	Long conical bushing	B_{lc}
Cylindrical thumb	Th_{c}	Short conical bushing	B_{shc}
Cylindrical cut thumb	Th_{cc}	Centres rigid or rotating	C_{rr}
Cylindrical mandrel	M_{c}	Floating centres	C_{fl}

If the described system is applied to a specific workpiece, it is observed that not all BSs can be used for a given workpiece, which is determined by the geometric incompatibility of the workpiece surfaces and the BEs that implement it. Therefore, research is needed aimed at a joint analysis of all possible BSs and workpieces of different configurations.

An analysis was conducted, with the help of which the criteria for geometric compatibility were defined, allowing the selection of a BS satisfying the geometric shape of the workpiece:

1. With a combination of shapes of the base surfaces, the following theoretical BSs are most often realized: MLTB+DS+S and MLTB+G+S or DG+S+S and DG+G
2. Presence on the first auxiliary LTB of casting or stamping slopes that do not allow the use of basing supports or support plates, as well as basing sleeves and mandrels (when basing on cylindrical surfaces). In this case, bevelled short basing prisms are used as BE.
3. The presence of casting or stamping slopes on the second auxiliary LTB does not allow the use of base supports or support plates, as well as basing sleeves or mandrels (when basing on cylindrical surfaces). Bevelled short movable basing prisms are used.
4. The geometric shape of the second auxiliary LTB does not allow the use of base supports and base plates. Short base prisms or bushings are used.
5. The presence of protruding elements on the surface used for the double-guide LTB (DS) (e.g. a stepped shaft based on an end step) does not allow the use of long base sleeves.

The obtained criteria can be presented in the form of a table (Table 2.5), allowing the selection of possible BSs.

Table 2.4 *Possible schemes for full basing of workpieces*

Theoretical scheme of basing	Combination of surfaces (FBP)	Implementations	Theoretical scheme of basing	Combination of surfaces (FBP)	Implementations
	PPP	SSS			PrlSS
	PPCylos	SSS		CylosPP	BlcSS
		SSPr$_{sh}$		CylosPCylos	PrlSS
	PPCylis	SSTh$_{cc}$			BlcSS
		SSS			PrlSPrshm
MLTB+G (DS) + S	PCylos	SPrlmS			BclSPrshm
		SPrshS			
		SBshcS		CylosPCylis	PrlSThcc
		SSS			BclSThcc
	PCylosCylos	SPrshS		CylosCylos	PrlPrsh
		SBshcS			BclPrsh
		SSPrshm			PrlS
		SPrshPrshm			PrlSThcc
		SBshcPrshm		CylosCylosCylis	BclPrshmThcc
		SSThcc			PrlPrshmThcc
	PCylosCylis	SPrlcThcc			BclSThcc
		SPrshThcc	DG+S+S (DG+G)		
		SBshcThcc		CylosCylis	PrlThc
	PCylisP	SThcS			BclThc
		SMccS			PrlThccThcc
		SThcS		CylosCylisCylis	BclThccThss
		SMccS		CylisPP	McSS
	PCylisCylos	SMccPrshm		CylisPCylos	McSS
		SThcPrshm			McSPrshm
	RCylisCylis	SThcThcc		BPB	McSThcc
		SMccThcc		CylisCylosCylis	McSThcc
		SCflThcc			McPrshmThcc
	CosP	BlcS			McThc
	CosCylos	BlcPrshm		CylisCylis	McMcc
	CosCylis	BlcThcc		CisCisP	CrrCrrS
SR+S	CisP	MconS	SC+DS+S		CflCflS
	CisCylos	MconPrshm			
	CisCylis	MconThcc			

An analysis of the BE structures in the special fixtures was carried out (Table 2.7), on the basis of which the criteria for their selection were determined:

1. Theoretical basing scheme;
2. Surface shape used for LTB;
3. Presence of protrusions or steps, with a size greater than 60 mm, on the surface used for LTB;
4. Quality of the surface used for the LTB;
5. Orientation of the BE (bottom, side, top);
6. Possibility of combining with another BE;

7. Maintainability.

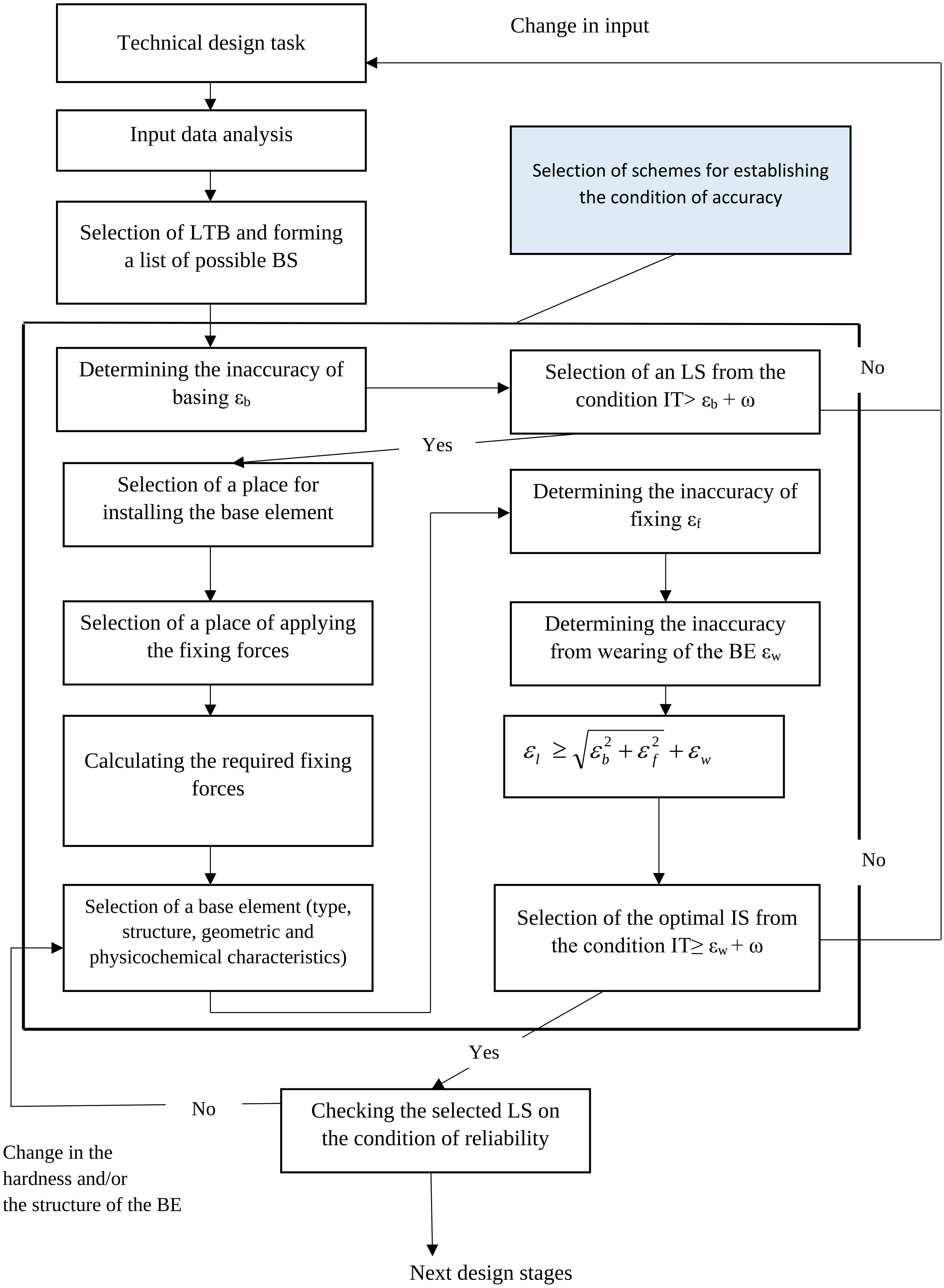


***Fig. 2.2** Choosing a rational location scheme*

Table 2.5 *Selection of a base scheme based on geometric compatibility criteria*

Combination of surfaces (FBP)	Implementations	Criteria									
		1						2	3	4	5
		MLTB +G+S	MLTB +DS+S	DG+S+S	DG+G	SR+S	SC+DS +S				
PPP	SSS	*									
PPCylos	SSS	*									
	SSPrshm	*								*	
PPCylis	SSThcc	*									
PCylosP	SSS	*	*								
	SPrlmS		*					*			
	SPrshS		*					*			
	SBcshS		*								
PCylosCylos	SSS	*	*								
	SPrshS		*					*			
	SBcshS		*								
	SSPrshm	*	*						*		
	SPrshPrshm		*					*	*		
	SBcshPrshm		*						*		
PCylosCylis	SSThcc	*	*								
	SPrlmThcc		*					*			
	SPrshThcc		*					*			
	SBcshThcc		*								
PCylisP	SThccS		*								
	SMccS	*									
PCylisCylos	SThcS		*								
	SMccS	*									
	SMccPrshm	*								*	
	SThcPrshm		*						*	*	
PCylisCylis	SThcThcc		*								
	SMccThcc	*									
	SCflThcc		*								
CylosPP	PrlSS			*							*
	BchlSS			*							
CylosPCylos	PrlSSS			*							*
	BclSS			*							
	PrlSPrshm			*					*	*	*
	BclSPrshm			*					*	*	
CylosPCylis	PrlSThcc			*							*
	BclSThcc			*							

Table 2.5 *Selection of a base scheme based on geometric compatibility criteria (continued)*

Combination of surfaces (FBP)	Implementations	Criterion									
		1						2	3	4	5
		MLTB +G+S	MLTB +DS+S	DG+S+S	DG+G	SR+S	SC+DS +S				
CylosCylos	PrlPrsh				*						*
	BclPrsh				*						
	PrlS				*						*
CylosCylosCylis	PrlSThcc			*							*
	BclPrshmThcc			*							
	PrlPrshmThcc			*							*
	BclSThc			*							
CylosCylis	PrlThc				*						*
	BclThc				*						
CylosCylisCylis	PrlThccThcc			*							*
	BclThccThcc			*							
CylisPP	McSS			*							
CylisPCylos	McSS			*							
	McSPrshm			*					*		
BtPBt	McSThcc			*							
CylisCylosCylis	McSThcc			*							
	McPrshmThcc			*							
CylisCylis	McThc				*						
	BcshS				*						
CosP	BclPrshm					*					
CosCylos	BclThcc					*					
CosCylis	MconS					*					
CisP	MconPrshm					*					
CisCylos	MconPrshm					*					
CisCylis	MconThcc					*					
CisCisP	CrrCrrS						*				
	CflCflS						*				

The values of the criteria are given in Table 2.6.

For the selection of the LS according to the criterion of processing accuracy, algorithms have been developed for determining the inaccuracies of basing εσ, using dependencies obtained by analysing the possible types of combinations of the base surfaces of the workpieces and the working surfaces of the base elements. Three types of combinations that determine the modules have been considered (Fig. 2.3): *“plane-plane"* , *“cylinder-prism* ”, *“cylinder-cylinder”.* In most cases, the accuracy of the technological size is influenced simultaneously by two bases, therefore an additional “*combined*” module is introduced. The inaccuracy of basing in *the combined module* is determined for two dimensional types - *linear* and *angular*.

Table 2. 7 *Solid models of base elements*

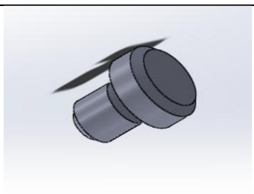
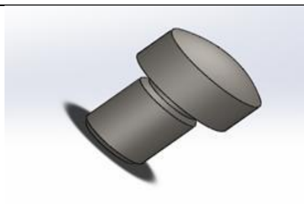
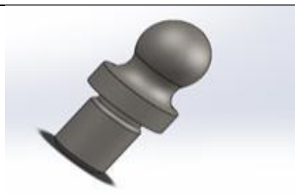
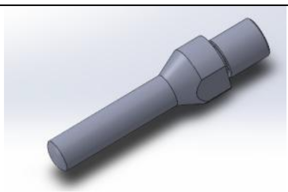
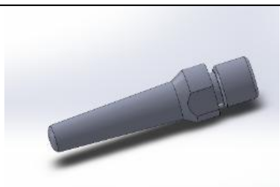
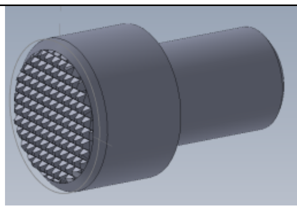
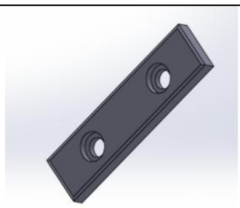
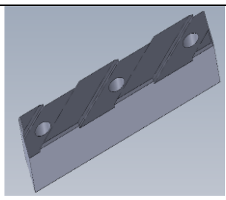
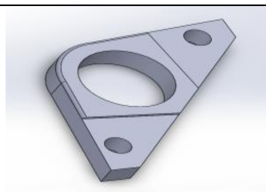
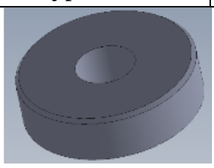
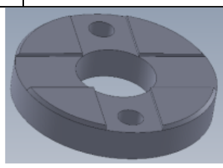
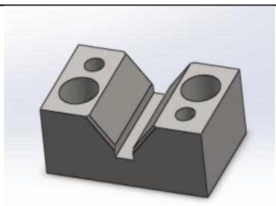
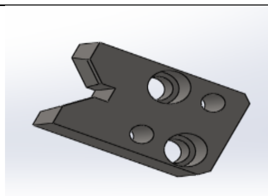
Basic elements for installing on flat surfaces		
 cylindrical support with flat head	 cylindrical support with spherical head, type1	 cylindrical support with spherical head, type 2
 Long cylindrical support with spherical head, type 3	 Long cylindrical support with spherical head, type 4	 cylindrical support with serrated head
 support flat type1	 flat support type 2	 flat support type 3
 thrust washer type1	 thrust washer type 2	
Base elements for locating on external cylindrical surfaces		
 long prism type 1	 long prism type 2	

__Table 2.7__ Solid models of base elements (continued)

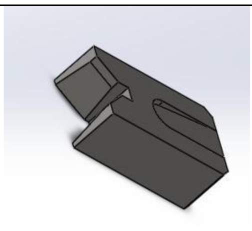
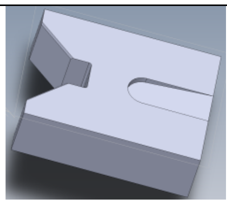
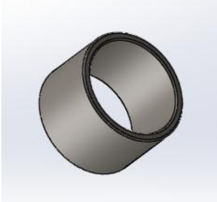
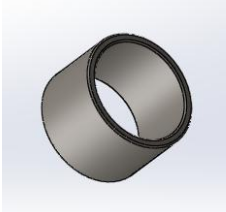
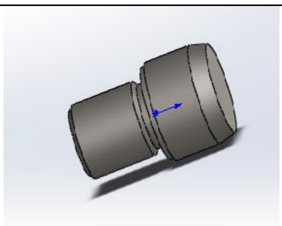
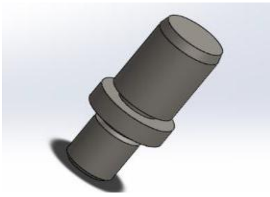
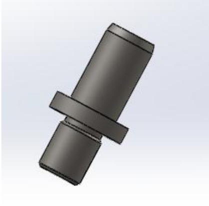
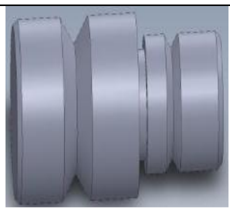
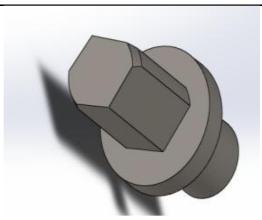
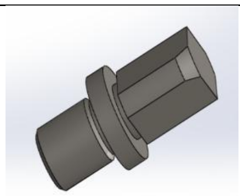
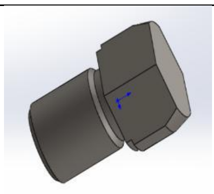
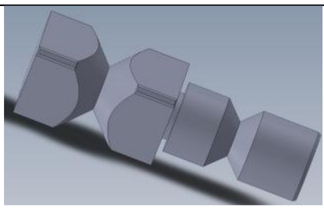
Base elements for locating on external cylindrical surfaces	
 Short prism type 1	 Short prism type 1
 short cylindrical bushing	 long cylindrical bushing
Base elements for installing on internal cylindrical surfaces	
 thumb cylindrical type 1	 thumb cylindrical type 2
 thumb cylindrical type 3	 thumb cylindrical type 4
 thumb cut type 1	 thumb cut type 2
 thumb cut type 3	 thumb cut type 5

Table 2.6 *Criteria for selecting base elements*

Base element	Type	Criterion 1					Criterion 2			Criterion 3		Criterion 4			Criterion 5		Criterion 6		Criterion 7	
		S	DS	G	DG	MLT B	P	Cylos	Cylis	1	2	Clean	Rough	With slope	From bottom	On the side	yes	no	yes	no
cylindrical flat head support		*	*	*		*	*	*		*		*			*	*		*		*
cylindrical support with spherical head	1	*	*	*		*	*			*			*		*	*		*		*
	2	*	*	*		*	*			*			*		*	*		*		*
	3										*									
	4										*									
support cylinder with cogged head	"	*	*	*		*	*			*			*		*	*		*		*
support flat (plate)	1	*		*		*	*			*		*				*		*		*
	2					*	*			*		*			*			*		*
	3					*	*			*		*				*	*			*
supporting washer	1	*				*	*			*		*			*	*		*	*	
	2	*				*	*			*		*			*	*	*			*
prism long	1				*			*				*			*			*		*
	2				*			*				*			*			*		*
short prism	1			*				*					*	*	*	*		*		*
	2			*				*				*			*	*		*		*
cylindrical thumb	1		*						*			*			*	*		*		*
	2		*						*			*			*	*		*		*
	3		*						*			*			*	*		*		*
	4		*						*			*			*	*	*			*
thumb cut	1	*							*			*			*	*		*		*
	2	*							*			*			*	*		*		*
	3	*							*			*			*	*	*			*
	4	*							*			*			*	*	*			*

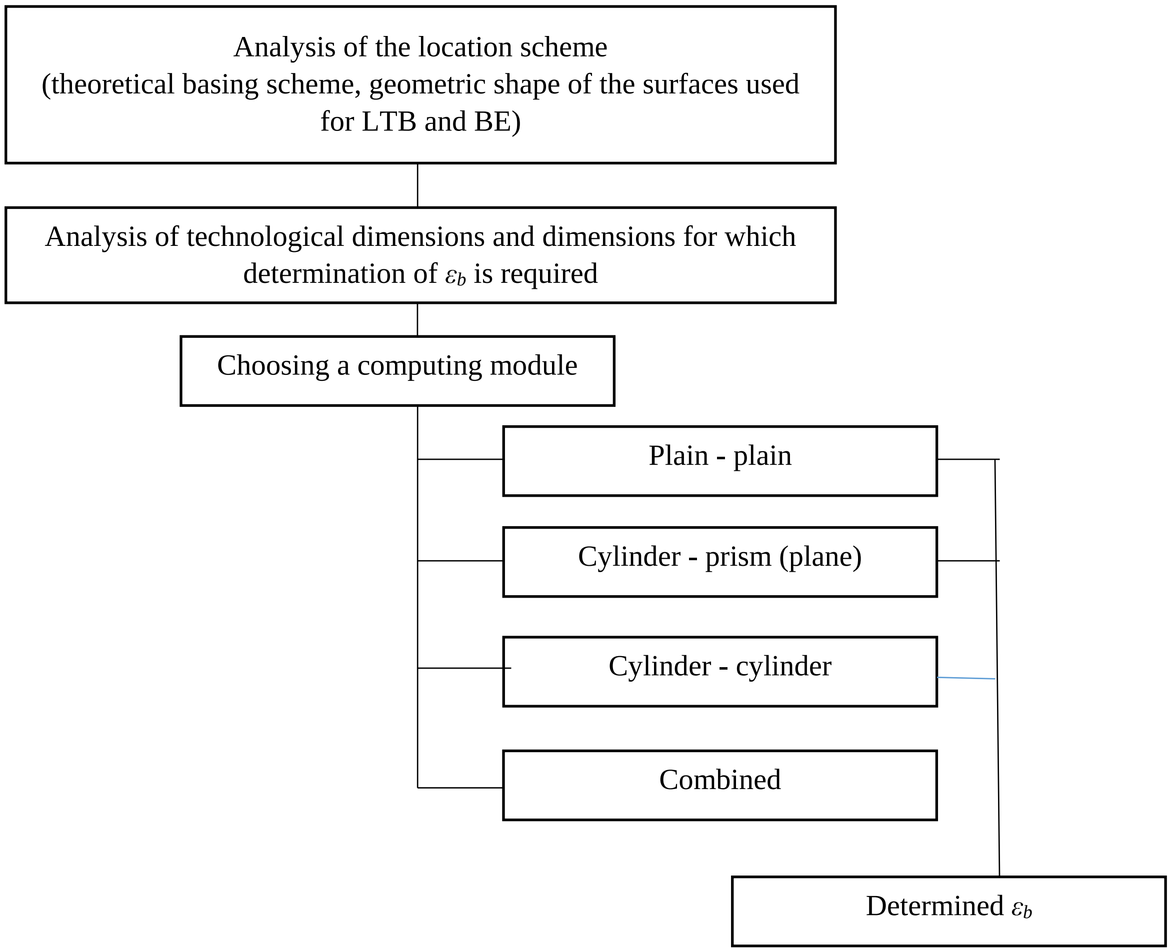


Fig. 2.3 *Selection of a calculation module for determining the basing inaccuracy*

An algorithm has been developed and dependencies have been proposed for determining the dimensions of the foundation elements depending on the foundation scheme, with BEs being divided into two types - *guiding* and *supporting* (Fig. 2.11).

When designing fixtures, one of the tasks that must be solved is ensuring their operability for a certain period of time until the planned repair. For this purpose, it is necessary to seek optimal solutions regarding the choice of material, method of strengthening treatment and design of the BE (e.g. quick-change BE). The choice of the location scheme in this case is carried out from the *reliability condition.*

The selection of material, strengthening treatment method or BE structure can be done in the following order:

1. The allowable wear of each BE is determined from the accuracy condition (1), after which the reliability condition (3) is checked.
2. If the reliability condition is not met, a more effective method of strengthening the BE is selected, after which a strength check is performed, based on the physical and mechanical characteristics. If the strength check is met, a repeated reliability check is performed. If the strength condition is not met, the selected BE cannot be used and it is

necessary to adopt: a change in the design of the BE or the selection of methods to increase the wear resistance of the BE; a change in the theoretical foundation scheme.

3. If the reliability condition is met, the considered LS (location scheme) is accepted and the next stages of fixture design are proceeded with.

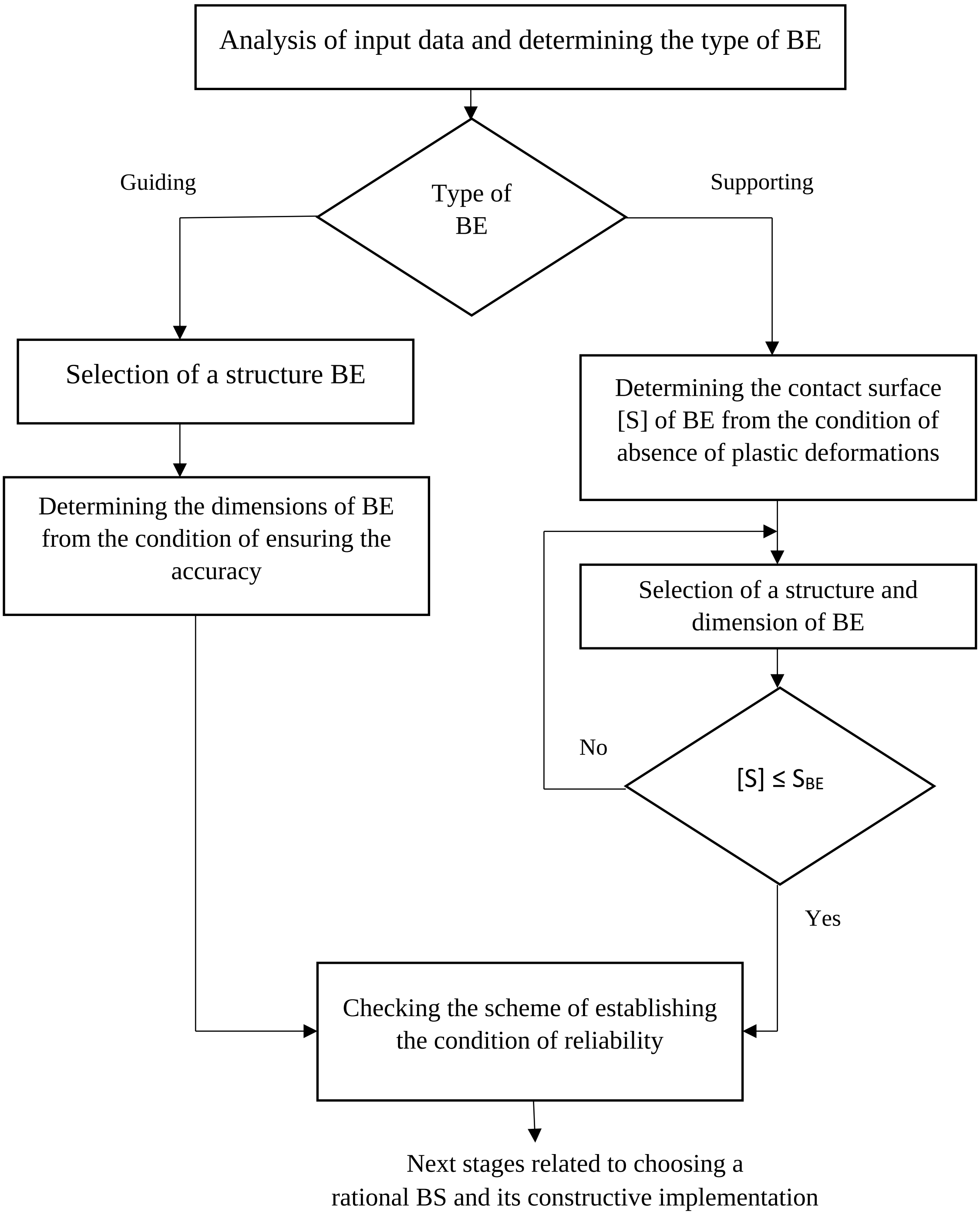


Fig. 2.11 *Block diagram for determining the dimensions of the BE*

For several IS meeting the conditions for accuracy and reliability, it is necessary to make an additional selection based on the criterion of minimum costs for the design and manufacture of the fixture P_{min}.

CHAPTER THREE

AUTOMATION OF THE SELECTION OF THE OPTIMAL SCHEME FOR LOCATION OF THE WORKPIECE WITH THE HELP OF HA CAD SYSTEMS

As the main approach to solving the task of automating the selection of an optimal location scheme and its constructive implementation, the systematic approach has been adopted, allowing to break down the entire optimization task into separate stages, to highlight the connections between them and the criteria for optimal search (Fig. 3.1). To solve the task of automating the design of an optimal IS, the object-oriented approach has been applied.

General task for optimization of the establishment scheme

Optimization of the location scheme according to the criteria of geometric compatibility

Optimization of the location scheme of according to the criterion of accuracy

$$IT \geq \sqrt{\varepsilon_b^2 + \varepsilon_f^2} + \varepsilon_{bw} + \varepsilon_w + \omega \, ,$$

Optimization of the choice of structure and dimensions of BE

$$[S] \leq S \{F, C, \sigma_T\}$$

Optimization of the location scheme from the reliability condition and the method of selecting a strengthening treatment of the BE

$$HB_{BE} \geq [HB] \{[IBR], Q, W, S, t_o, [\varepsilon_w], ky, N, L, m, m_1, m_2\}$$

$$[IBR] \leq IBR \{Q, HB, F, t_o, [\varepsilon_w], ky, N, L, m, m_1, m_2\}$$

Optimization of the location scheme according to the criterion for minimum cost of design and production of the device P_{min}

$$P + C\,(1 + 0.01\lambda)^{T}\,(Aa + Ae)$$

Fig. 3.1. *Composition of the optimization task*

Based on the methodology developed in the second chapter and the above, a general scheme for automating the design of an optimal IS using a "mid-range" CAD system has been developed (Fig. 3.2).

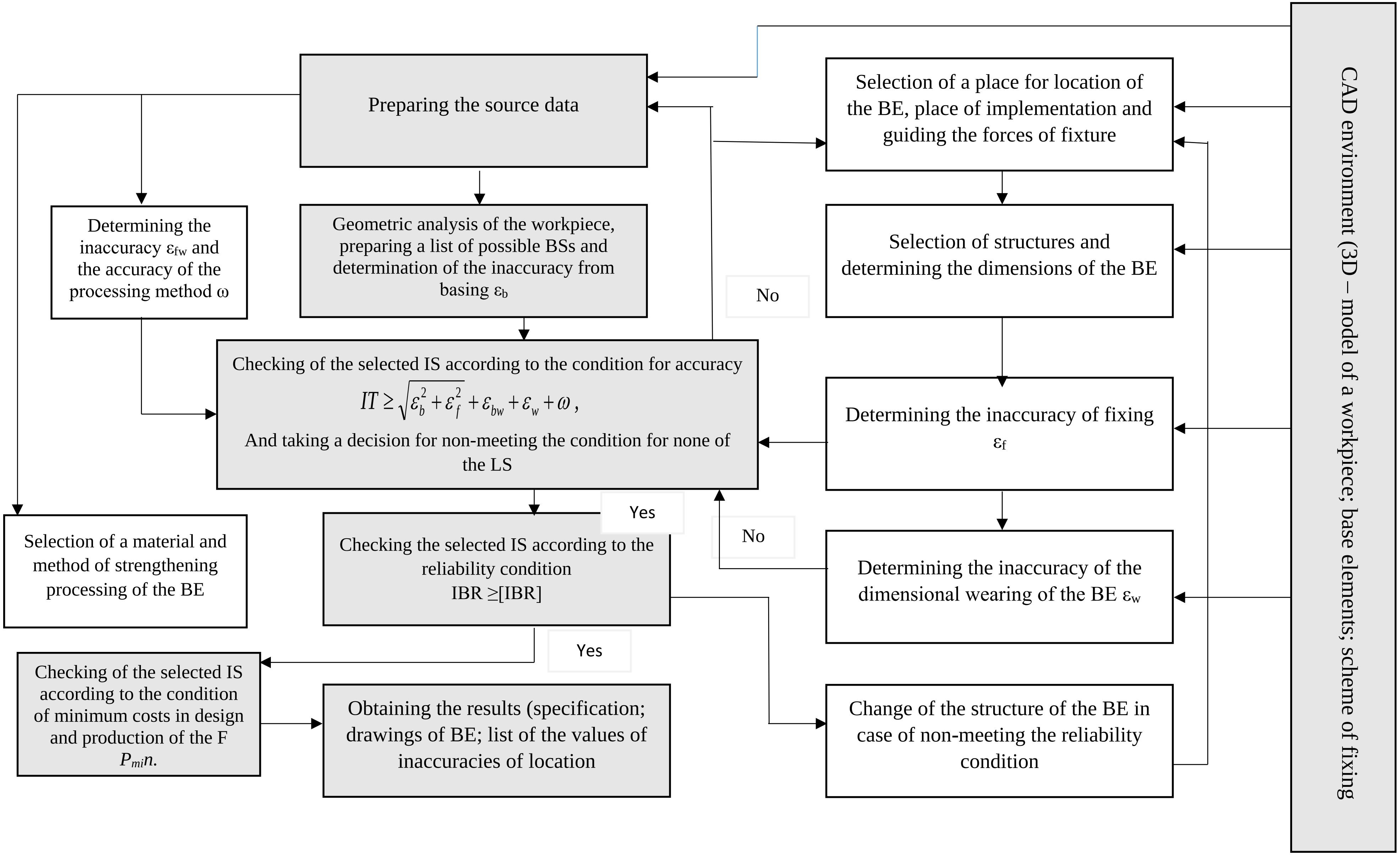


Fig. 3.2. *Diagram of automated design of optimal location scheme*

An algorithm for automated design of an optimal location scheme has been developed, according to which the optimization of the given scheme is carried out through modules for selecting the IS according to the criteria of accuracy, reliability and cost. Moreover, these modules perform the function of making a decision on the further course of the design according to the results of the check. The remaining modules, which are around them, are intended for determining the values of the IS parameters necessary for its analysis according to the criteria.

Through a joint analysis of the theoretical IS and the geometric shape of the workpiece, an automatic search for possible IS and calculation of the inaccuracy from the basing for each IS and for each technological size is performed.

The basic algorithm for forming a list of schemes for establishing and determining the inaccuracy of basing is shown in Fig. 3.4.

The selection of the BE includes two stages (Fig. 3.8): selection of the design and determination of the BE dimensions (from the condition of absence of plastic deformation in the contact area between the BE and the workpiece).

The selection of the BE design is carried out according to the scheme shown in Fig. 3.5, systematizing the BE design according to the criteria discussed in chapter two.

Determination of the actual contact area of the supporting BE is carried out using dependencies and the block diagram shown in Fig. 3.7.

Table 3.4 lists types of integrated BE M_{intBE} and their purpose in the design system.

The solid body models (T_T M) of BE are represented by a set of elementary primitives each of which consists of *m* forming surfaces S_{cros} and *j* guiding surfaces S_{ext}.

$$K_{БЕ}^{n}=\{V_{prof}\},n=1\ldots..N, \tag{3.2}$$

$$V_{prof}^{ml}=(\{S_{cros}\},m=1\ldots.M)\cup(\{S_{ext}\},l=1\ldots L) \tag{3.3}$$

$$S_{cros}^{i}=\{S_{ent}\},\ i=1\ldots.I, \tag{3.4}$$

$$S_{ext}^{j}=\{S_{ent}\},j=1\ldots.J\ , \tag{3.5}$$

where *i* is the number of forming profiles with dimension I; *j* - number of guide profiles with dimension *J*.

Each profile has design attributes, which are subsets of the DB of BE $A_{ent.\ tab}$, if such exists

$$Aent^{\,k}=\{\ Aent\ \},\ k=l\ \ldots.\ K\ , \tag{3.6}$$

where k is the number of attributes characterizing the surfaces.

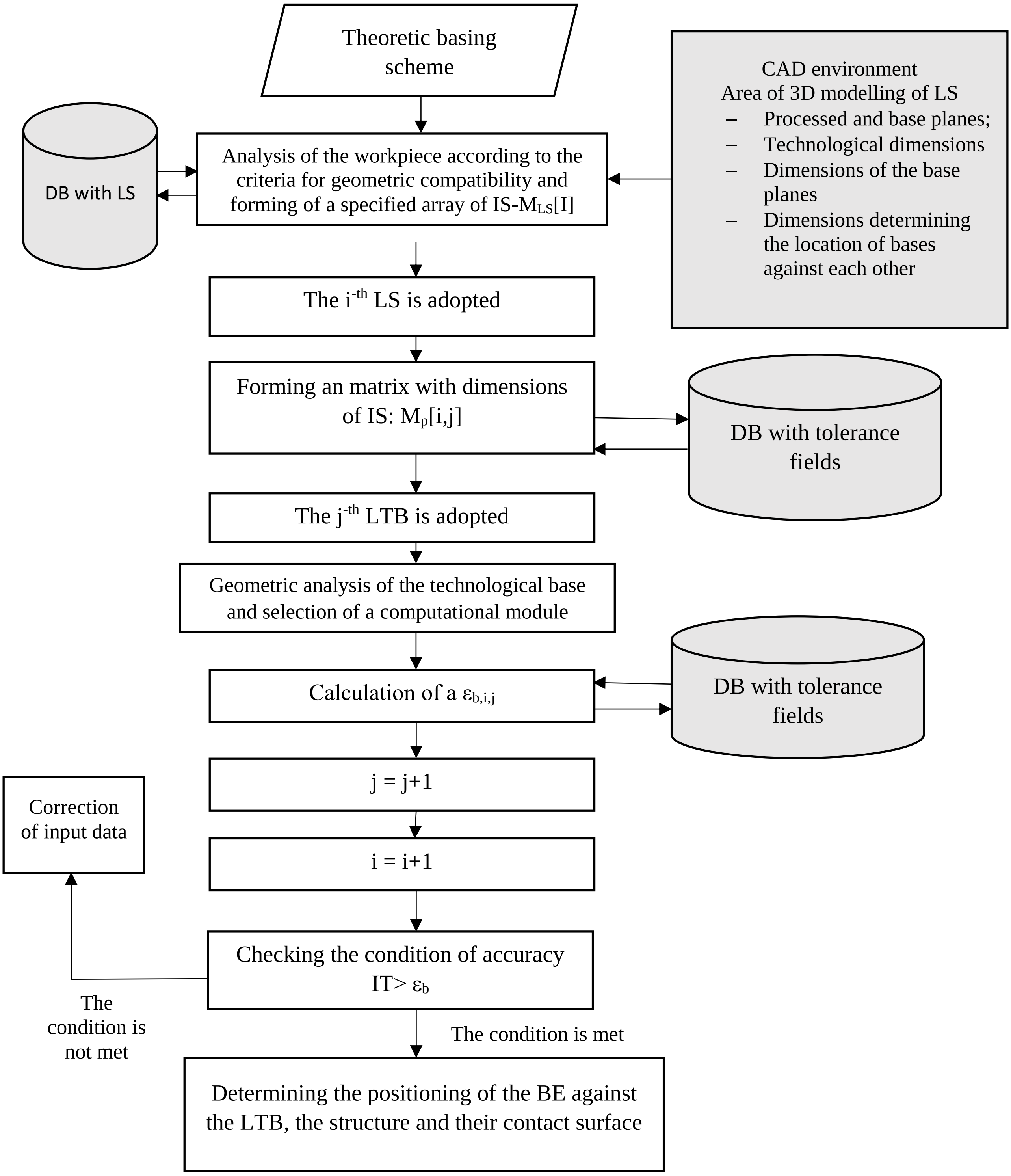


Fig. 3.4. *Scheme of formation of the LS and calculation of the inaccuracy from basing*

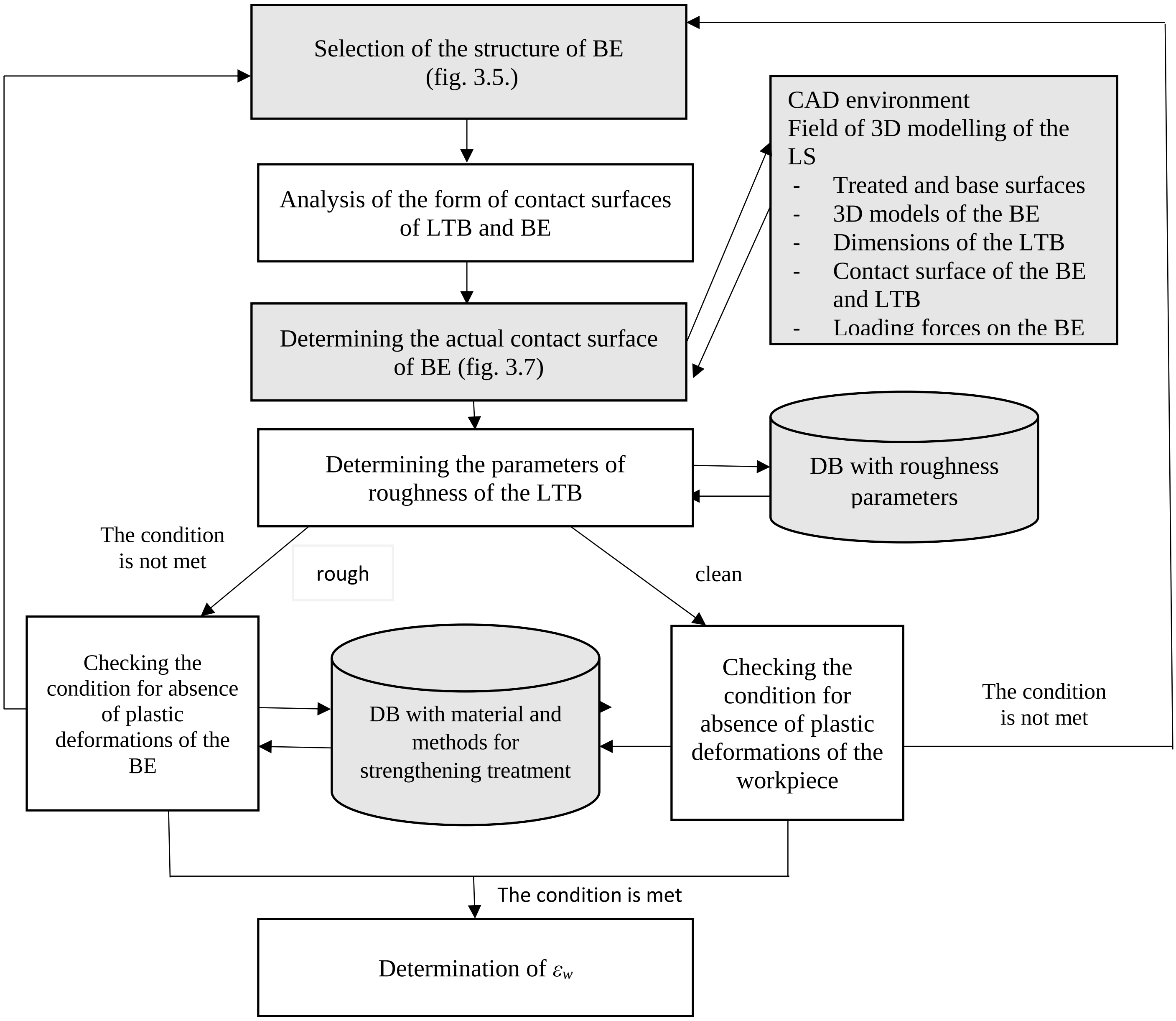


Fig. 3.8. *Scheme for selecting base elements*

Between the geometric and attribute DBs of BE, there is a connection between the fields of the tables of the geometry parameters and their attributes. Parameterization proceeds until the names of the parameters match (Fig. 3.9). Dependent parameters enter the DB of the attributes only as computational parameters in the field of technical requirements of the drawing. The layout models of BE of the fixtures can be stored in the DB in the form of a tree, built from separate structural elements (profiles), and also as a finished geometric object.

The determination of the inaccuracy of fastening εf is carried out from tables depending on the type and condition of the LTB, the type of BE, the fastening scheme and the dimensions of the workpiece or with the help of experimentally derived dependencies for the contact deformations in the contact point "*workpiece - BE*".

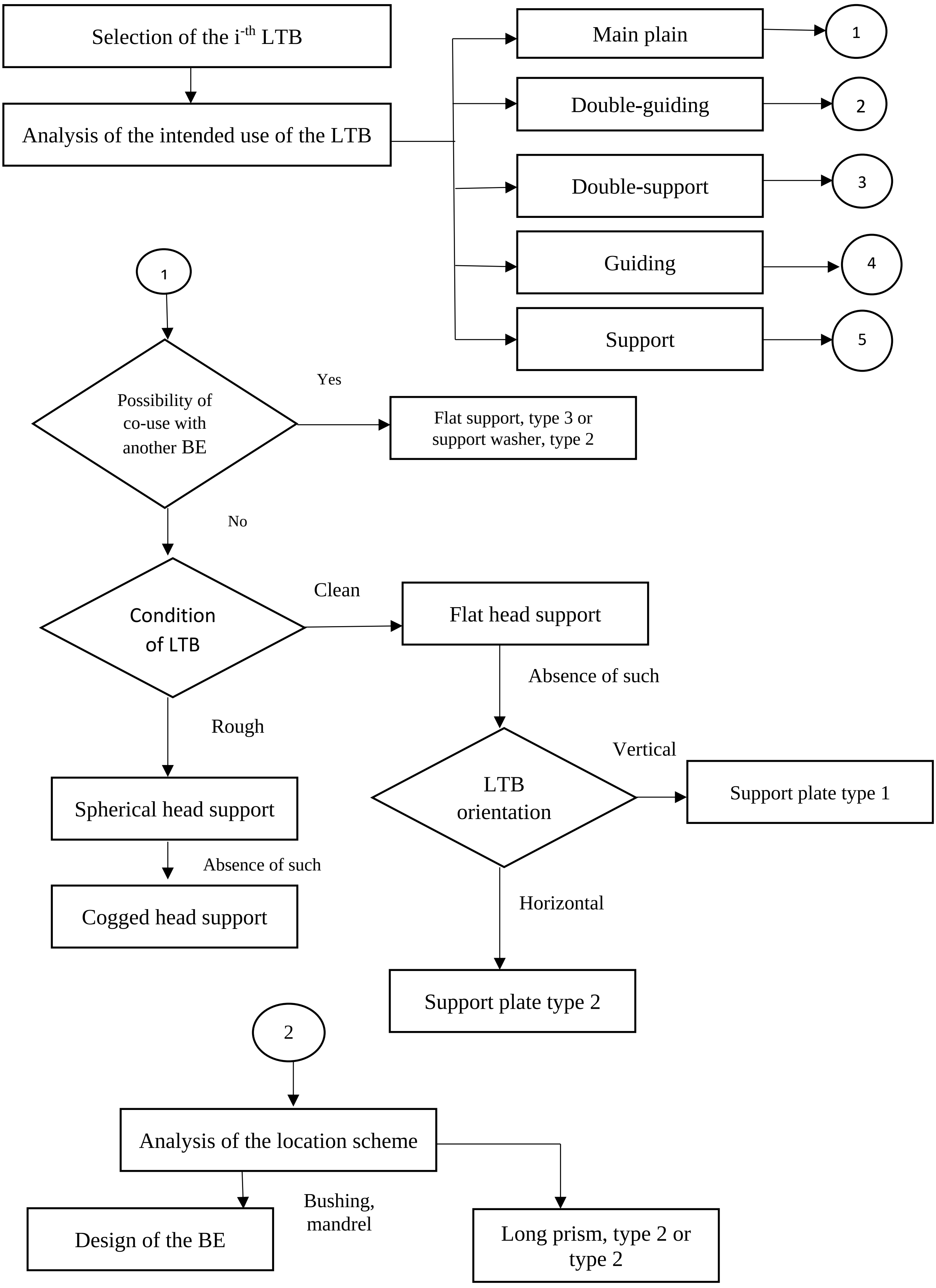


Fig. 3.5. *Selection of structure of the based elements*

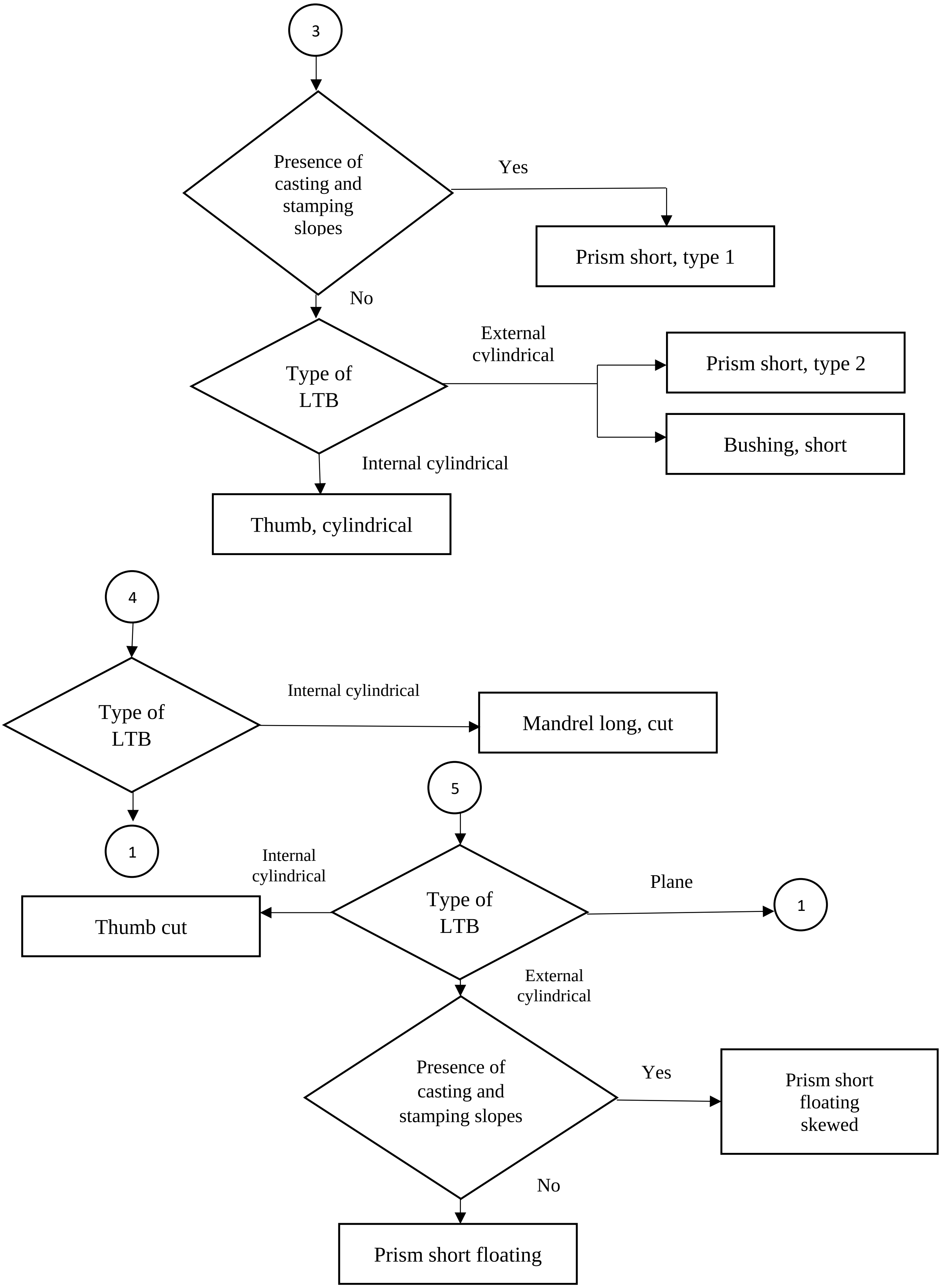


Fig. 3.5. *Selection of structure of based elements (continued)*

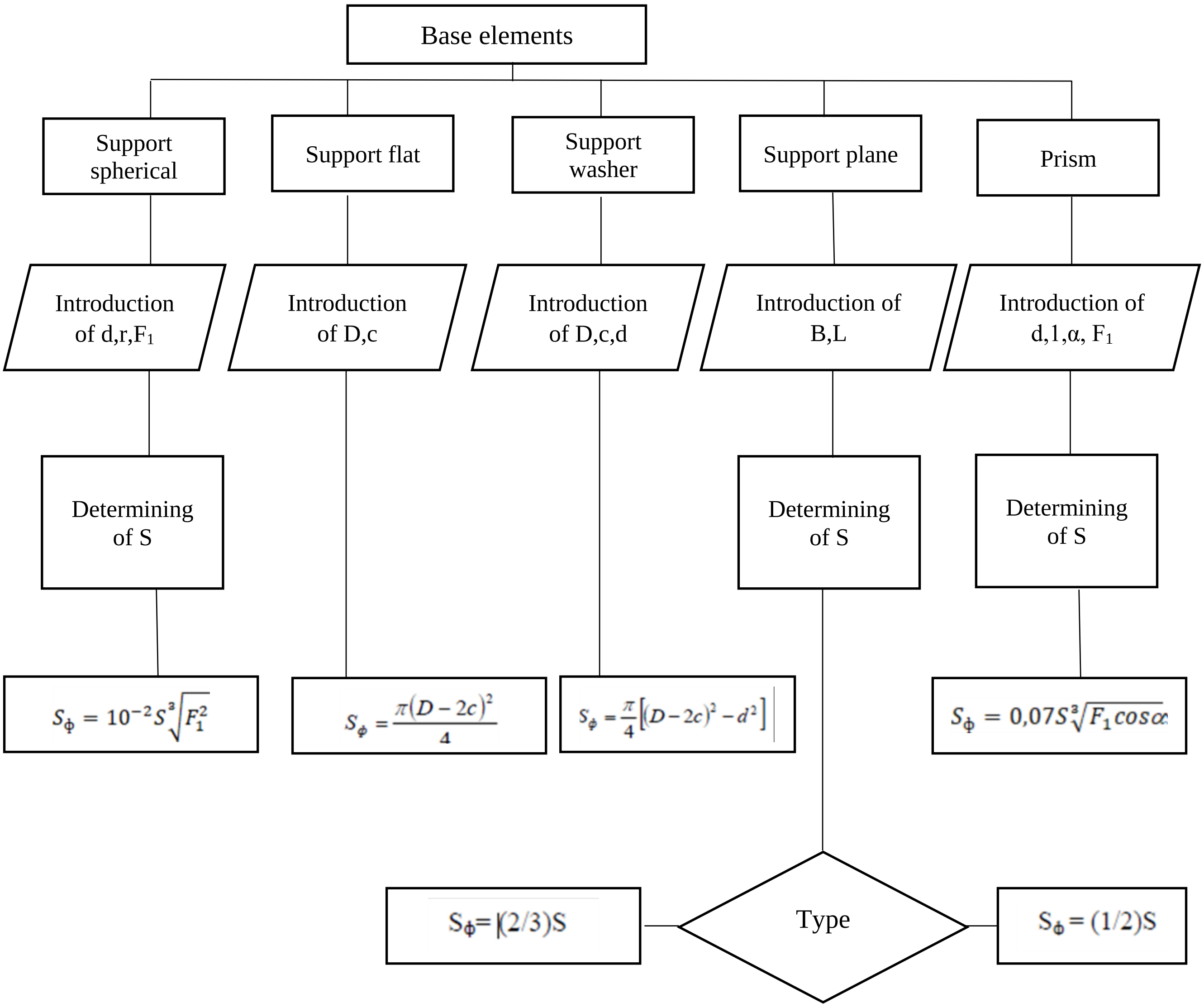


Fig. 3. 7. *Scheme for determining the contact area of the supporting base elements*

A diagram for determining the inaccuracy of fixing is shown in Fig. 3.10.

The determination of the dimensional wear of the BE εw, is carried out analogously to the inaccuracy of fastening using the dependencies according to the scheme shown in Fig. 3.11

Based on the obtained data on the load, the load conditions, the geometric and strength characteristics of the BE, the contact area with the workpiece and the permissible inter-repair interval [IM] set by the designer, a reliability check is performed at a certain inter-repair interval IM according to the dependence:

$$IBR = \frac{1{,}2[\varepsilon_u].\left(m - m_1 W - m_2 \dfrac{0{,}1Q}{S \cdot HV}\right)}{N.k_y\left(1 + 0{,}003L\right).0{,}79t_o} \geq [IBR], \qquad (3.14)$$

Table 3.4 *Types of integrated models of the BE of the fixtures*

Detail models *Mint.BE*	Designation	DB type	Project procedures
Space of the synthesis of the construction			
Solid body layout models	K_{BE}	Library T_TM	Construction and parameterization of T_TM Formation of a database of BE attributes
Project Calculation Environment			
General description	A_{BE} *TAB*	DB of the attributes of BE	Search for BE Formation of the attributes of T_TM and of the drawings
Dimensional parameters	*A-ent . tab*	DB with dimensional parameters	Selection of dimensional parameters Calculation of dimensional parameters
Search of parameters	*ZBE*	KB of ES	Parameter selection
Environment for the formation of project documents			
Working drawings	*LEE*	Working drawings library	Update by type of T_TM Formation of drawing attributes by DB with BE attributes
Drawings of group BE	*LEE.GR*	Group drawing library	Selection of dimensional parameters from DB Generating drawings

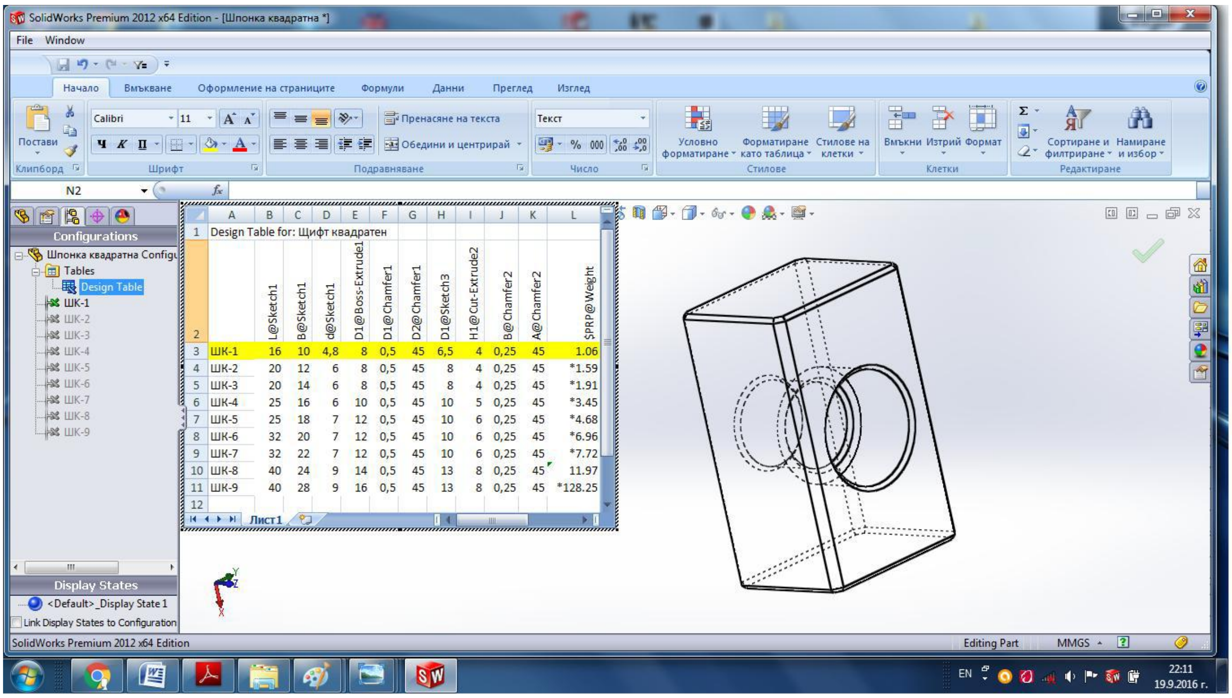


Fig 3.9 *Parameterization of the dimensions of the BE and the attributes of the dimensions for different BE configurations*

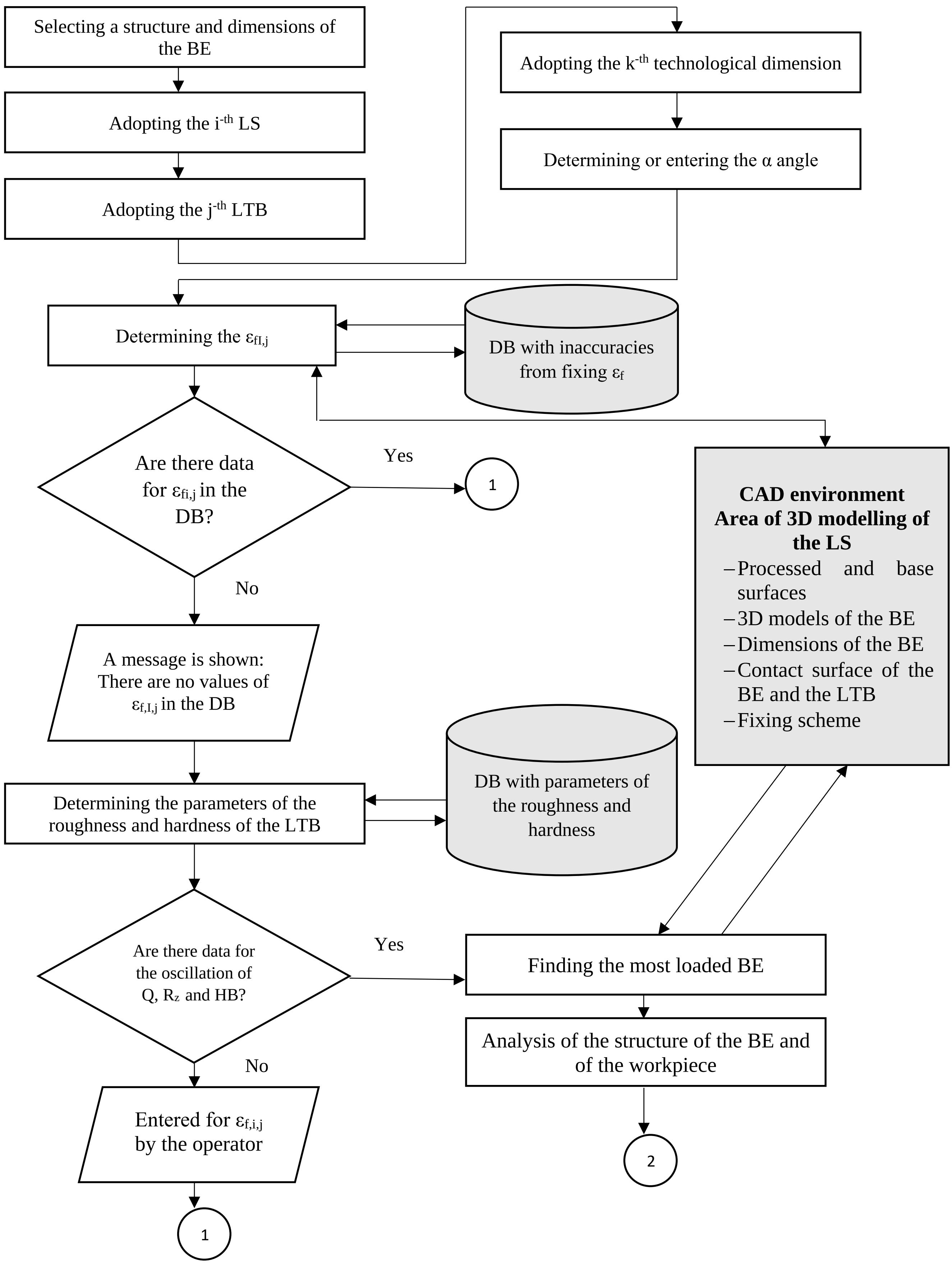


***Fig. 3.10**. Determination of the inaccuracy of fastening*

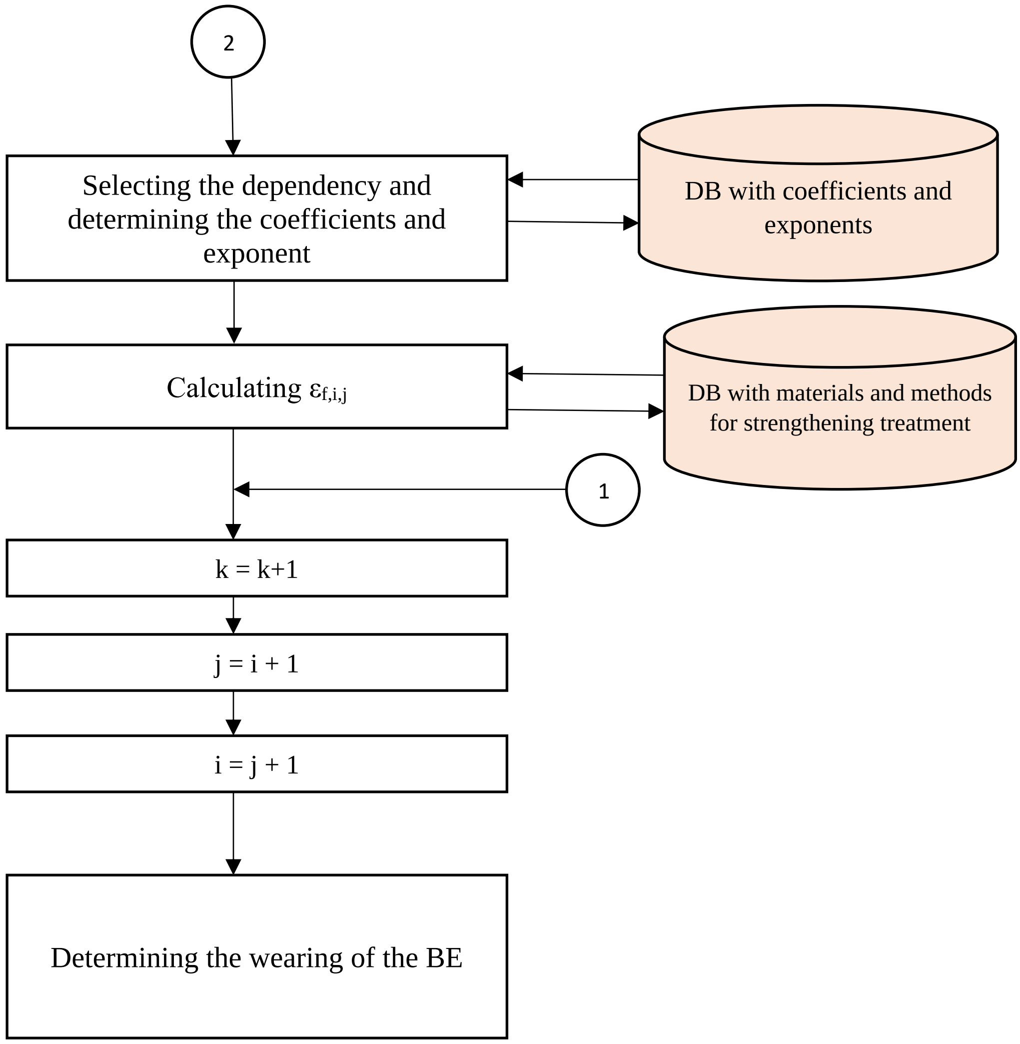


Fig. 3.10. *Determining of the inaccuracy of fastening (continued)*

where Q is the load on the support, N; HV - hardness of the BE, t_o - the main time for performing the operation, min; W - wear resistance criterion; S - contact area of the BE and the workpiece, mm^2 ; k_y - coefficient taking into account the processing conditions (material of the workpiece, processing method, cooling); m, m_1, m_2 - experimental coefficients; L- length of the workpiece sliding path along the BE until reaching the support, mm (determined approximately by the operating conditions).

The permissible dimensional wear of BE [ε_w] is determined after determining the economic accuracy of the processing method ω and the inaccuracies from basing ε_b and fastening εf according to the dependence

$$[\varepsilon_w] = 0{,}9\sqrt{(\mathrm{IT}-\omega)^2 - \varepsilon_b^2 - \varepsilon_f^2}.$$

The block diagram for checking the reliability of the IS is shown in Fig. 3.12.

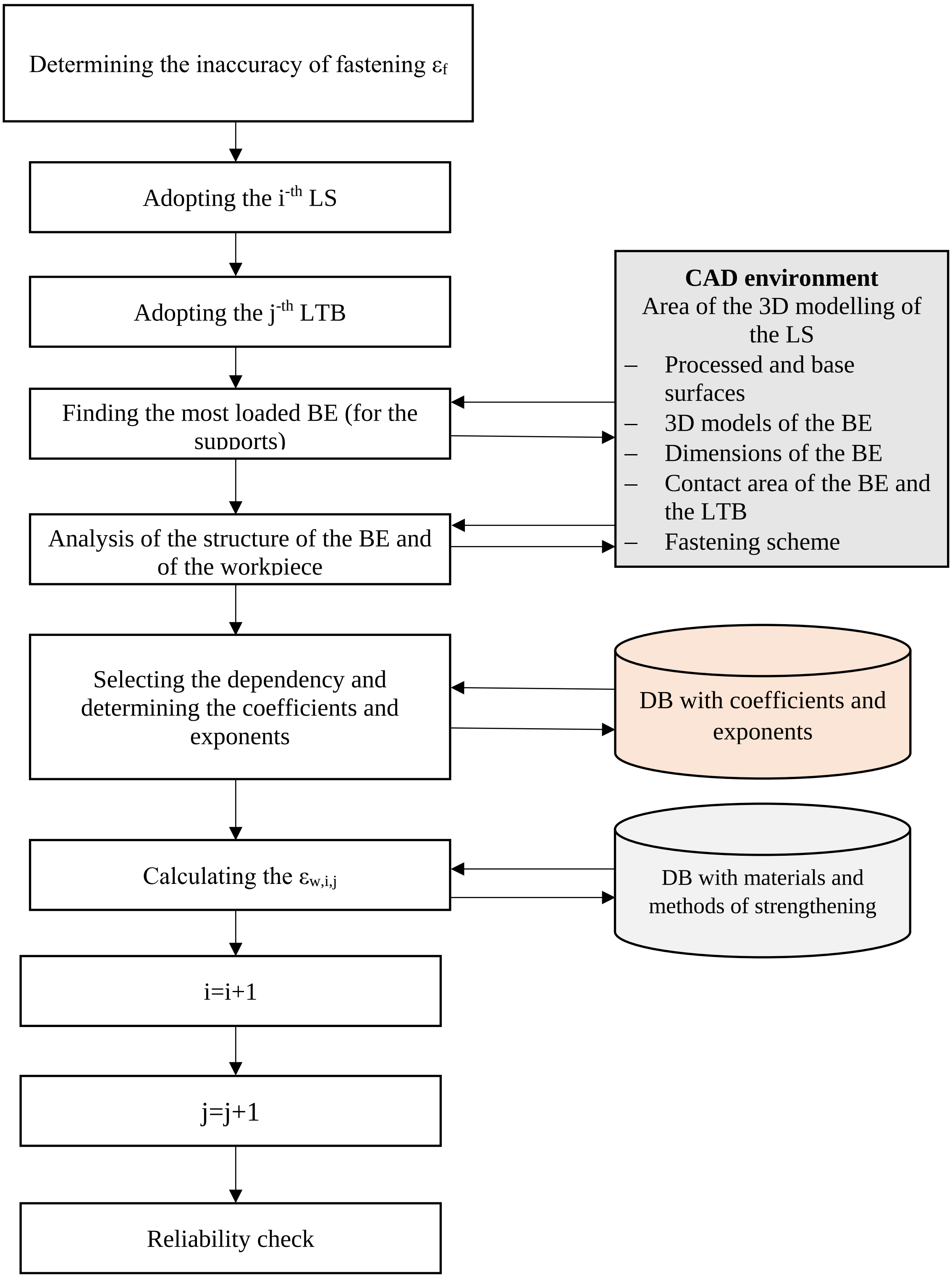


Fig. 3.11. *Determination of dimensional wear of the base elements*

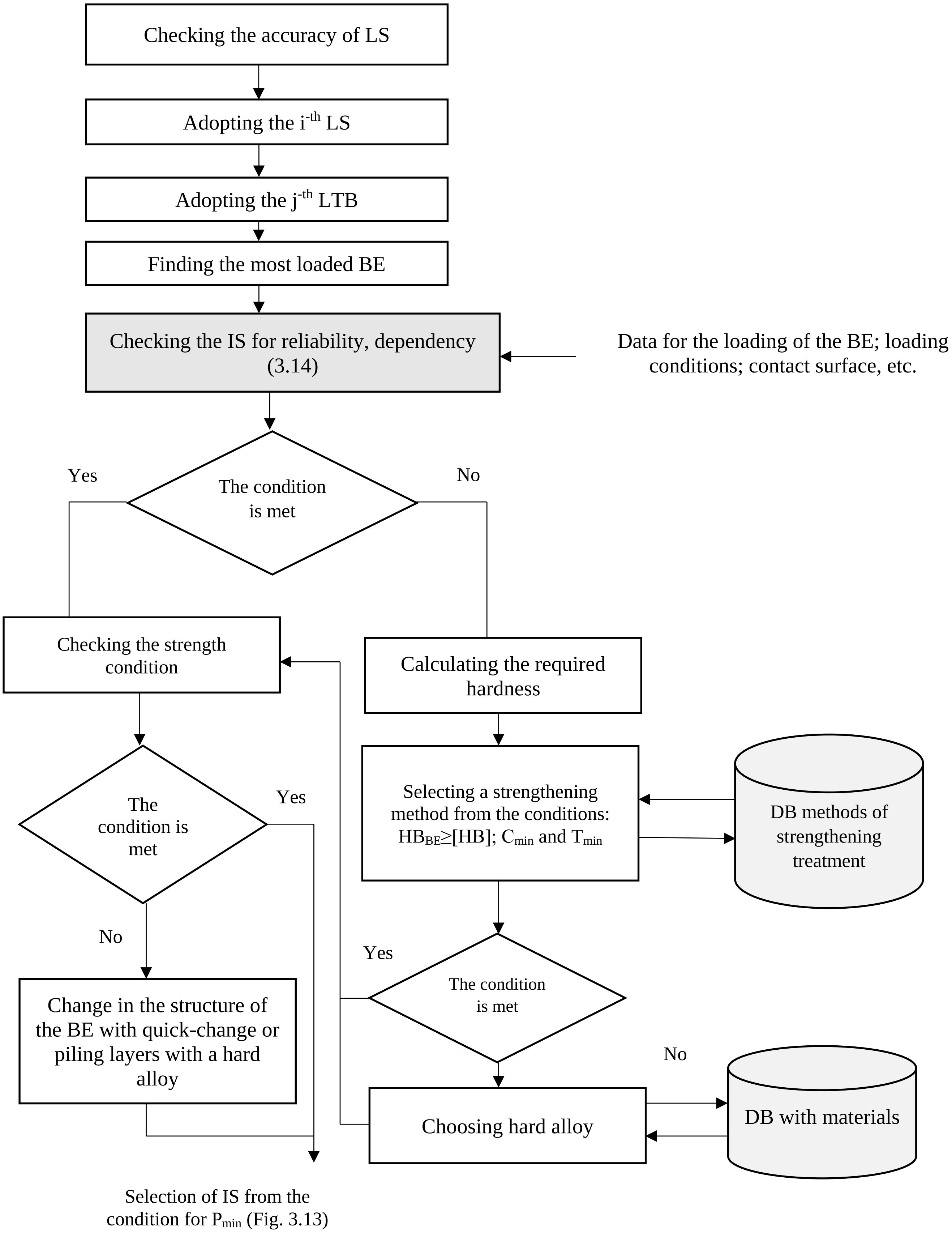


Fig. 3.12. *Checking the reliability of the IS and searching for a rational strengthening method*

If more than one LS is selected that meets the reliability condition, the one that provides the minimum costs for manufacturing the fixture P_{min} is selected, according to the methodology described in the second chapter and the algorithm shown in Fig. 3.13.

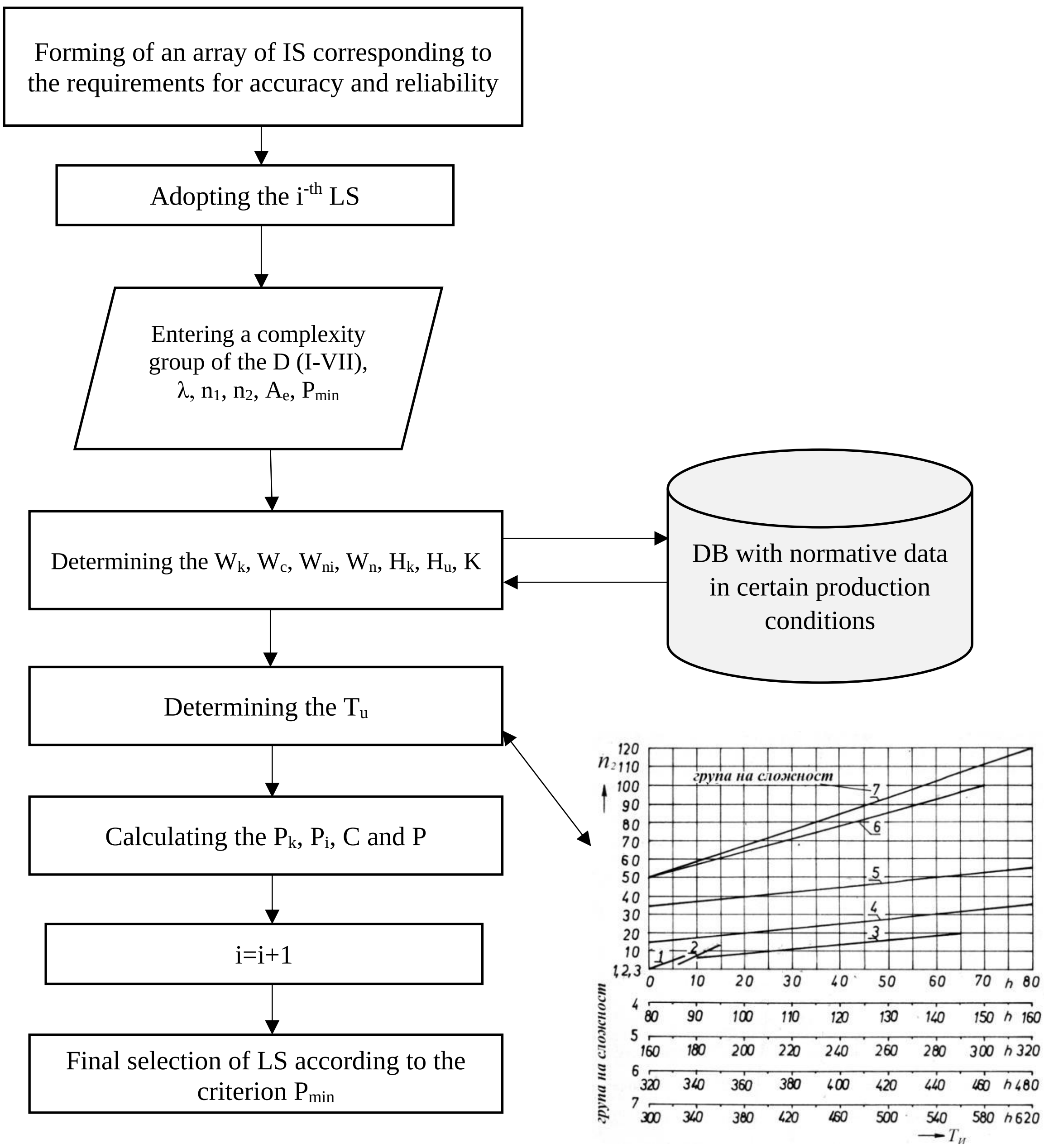


Fig. 3.13. *Selection of LS from the condition for minimum production costs for producing the fixture*

CHAPTER FOUR

MODELS AND GUIDELINES FOR AUTOMATED DESIGN OF OPTIMAL LOCATION SCHEME

The analysis of the model for selecting an optimal LS shows that the most suitable method for its program implementation is object-oriented programming, since the LS and BE of which it is composed are considered as objects for optimization, having certain characteristics and relationships. Therefore, it is rational to present the description of the structure, parameters and relationships of the IS and BE as classes containing data for the creation, analysis and optimization of objects. This simplifies the data exchange with the CAD system, since it considers each model and its elements as an object, described using a given class.

An essential part of an object-oriented system is *the class diagram,* which depicts the classes and the relationships between them, representing the logical model of the system.

The structural diagram of the classes and their logical connections is shown in Fig. 4.1. According to the diagram, the basis of the developed module is API application class making the connection with API SolidWorks and containing the classes LS and BE, as well as the functions and procedures for selecting an optimal LS

Because the SolidWorks system is strictly parametric, then all models in it are represented in the form of a tree of elements that are connected by parametric relationships. This allows each element to be viewed as an object of a certain class, interacting with other objects using functions and procedures describing parametric relationships.

The design object model is represented as a set of bodies, consisting of a set of surfaces and a table with the geometric and dimensional parameters of the given body. The parameter table describes the interface of the interactions of the MSExel tables for creating and editing the database of body design variants.

Having access to the object model, we can automatically move along its parameter tree and, if necessary, change the values of the model parameters.

In the structural diagram shown in Fig. 4.1, the workpiece and the BE are classes of bodies, the processed surfaces and the surfaces being the location technological bases (LTB) - classes of the surfaces, and the DB - classes of the parameter tables.

Since the class diagram shows only the logical structure of the system, and not its dynamics, it is necessary to form diagrams that reflect real changes. In object-oriented design, such diagrams are the transition diagram from one state to another (Fig. 4.2).

The structural diagram of the software product is shown in Fig. 4.3. The basis of the system are API classes providing access to SolidWorks functions and fully integrating the program module into its environment. It manages the execution of all functions and procedures, as well as the user interface. The main system's computational modules are exported as separate dynamic function libraries.

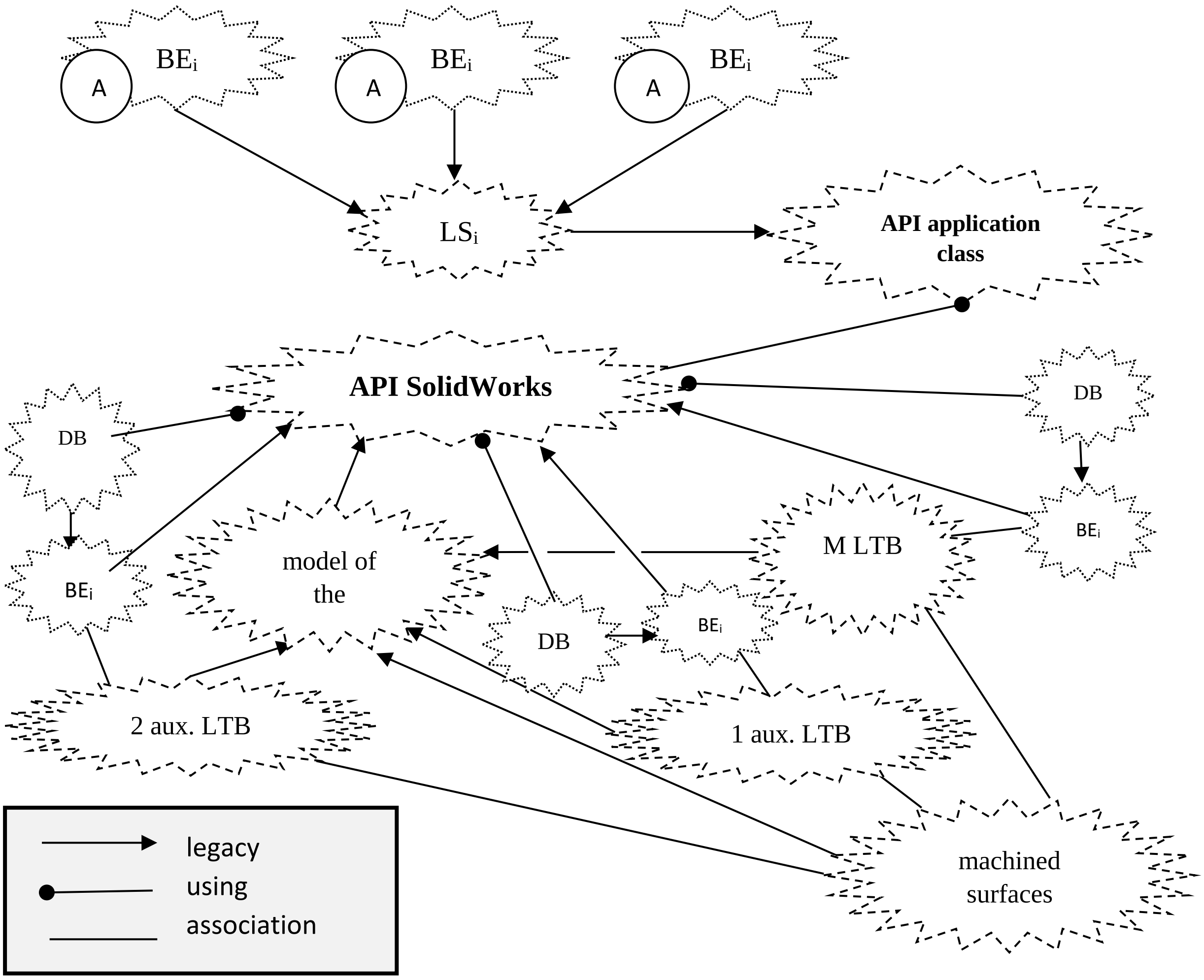


Fig. 4.1 *Structure of classes in CAD + CAD LS system (A - abstract class)*

For the software implementation of the automated system, a database of solid-state models of BE has been developed in the SolidWorks environment and tables for automated selection of their parameters in the MSExel environment (Fig. 4.5). The database allows the inclusion of new structure base elements.

For the automated selection of an optimal location scheme, it is necessary to develop a database with reference information containing data of different content and structure: tolerance fields; economic accuracy of processing methods; surface quality parameters after various processing methods; inaccuracies from fastening, etc.

Part of this database is stored in the form of separate spreadsheets, access to which is based on direct queries.

More complex is the organization of data storage for materials and methods of strengthening treatments.

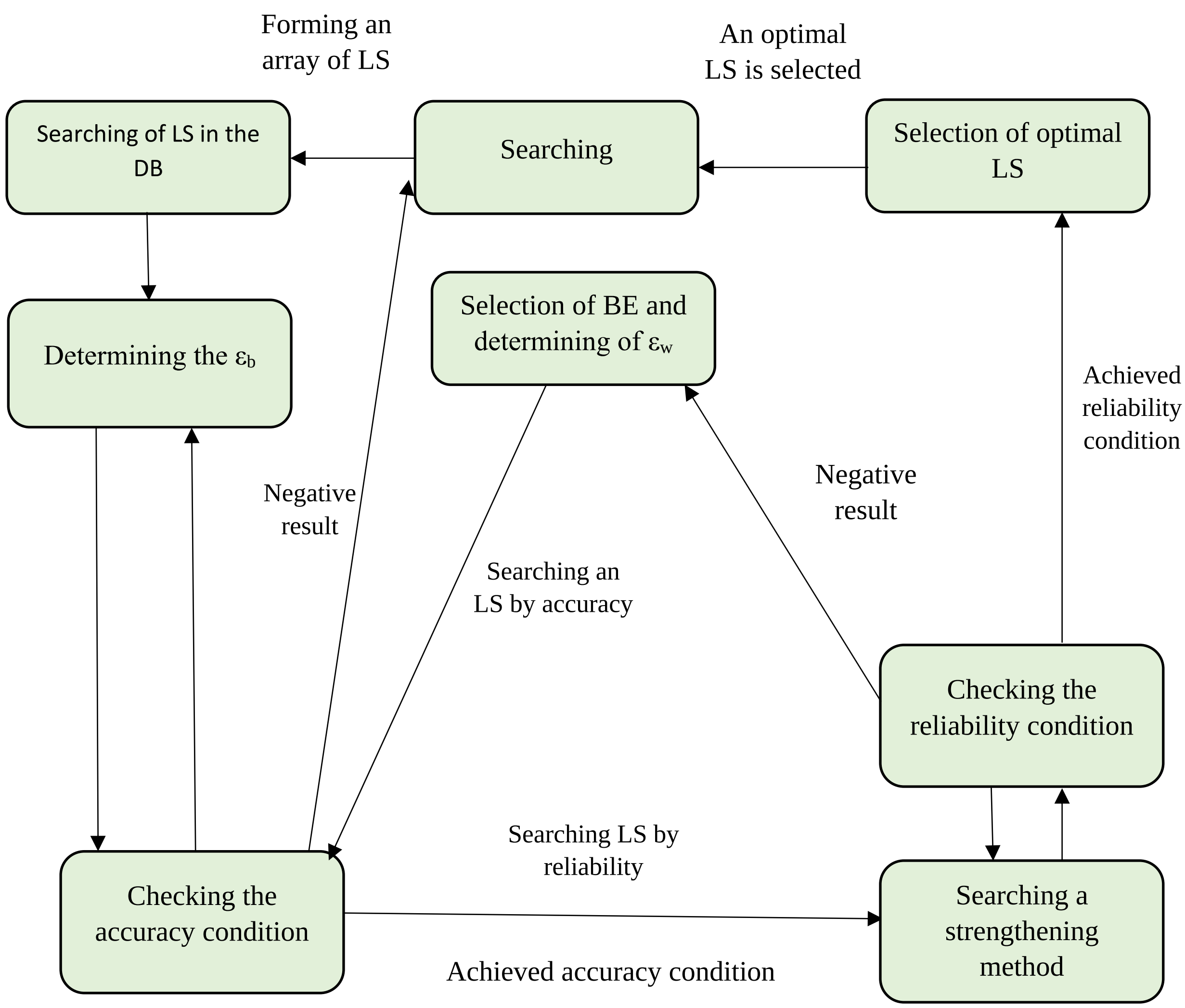


Fig. 4.2 *Design status diagram of an LS*

The most widespread are database management systems (DBMS) based on relational models. Therefore, it is rational to use such DBMS to develop a structure for storing data on materials and methods of strengthening.

A methodology has been developed for the practical implementation of the automated system for selecting an optimal location scheme, including the following stages:

- Creating a solid 3D model of the workpiece;
- Data entry for the technological operation;
- Indicating the surfaces used for location technological bases and generating a list of possible SDs;
- ***Module*** "Analysis of the geometric compatibility of the SD and the surfaces of the workpiece" and output of a specified list of SD;

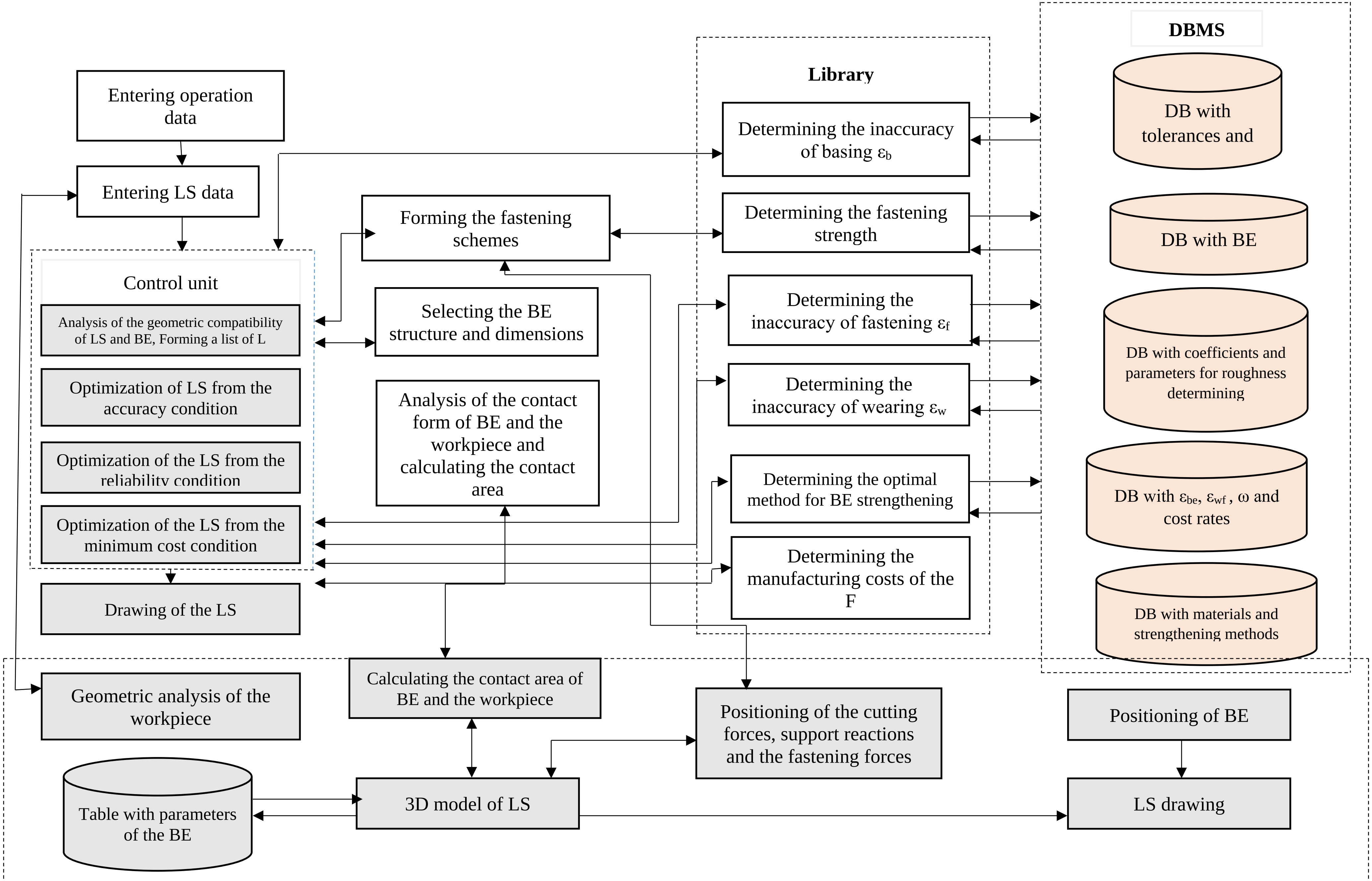
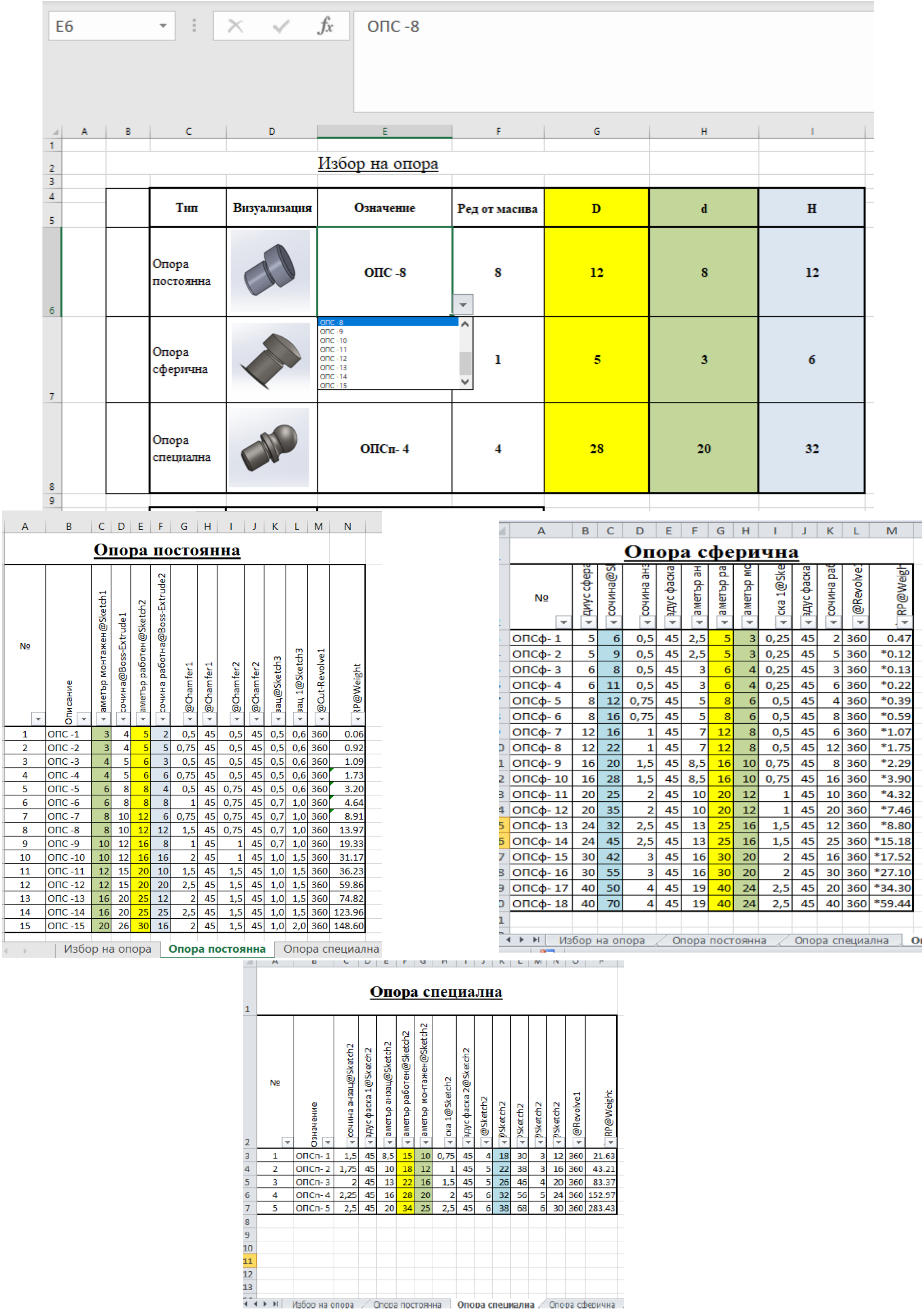


***Fig. 4.3** Structural model of the software package*



E6 ОПС -8

Избор на опора

Тип	Визуализация	Означение	Ред от масива	D	d	H
Опора постоянна		ОПС -8	8	12	8	12
Опора сферична		1	1	5	3	6
Опора специална		ОПСп- 4	4	28	20	32

Опора постоянна

№	Описание	аметър монтажен@Sketch1	сочина@Boss-Extrude1	аметър работен@Sketch2	сочина работна@Boss-Extrude2	@Chamfer1	@Chamfer1	@Chamfer2	@Chamfer2	зац@Sketch3	зац 1@Sketch3	@Cut-Revolve1	RP@Weight
1	ОПС -1	3	4	5	2	0,5	45	0,5	45	0,5	0,6	360	0.06
2	ОПС -2	3	4	5	5	0,75	45	0,5	45	0,5	0,6	360	0.92
3	ОПС -3	4	5	6	3	0,5	45	0,5	45	0,5	0,6	360	1.09
4	ОПС -4	4	5	6	6	0,75	45	0,5	45	0,5	0,6	360	1.73
5	ОПС -5	6	8	8	4	0,5	45	0,75	45	0,5	0,6	360	3.20
6	ОПС -6	6	8	8	8	1	45	0,75	45	0,7	1,0	360	4.64
7	ОПС -7	8	10	12	6	0,75	45	0,75	45	0,7	1,0	360	8.91
8	ОПС -8	8	10	12	12	1,5	45	0,75	45	0,7	1,0	360	13.97
9	ОПС -9	10	12	16	8	1	45	1	45	0,7	1,0	360	19.33
10	ОПС -10	10	12	16	16	2	45	1	45	1,0	1,5	360	31.17
11	ОПС -11	12	15	20	10	1,5	45	1,5	45	1,0	1,5	360	36.23
12	ОПС -12	12	15	20	20	2,5	45	1,5	45	1,0	1,5	360	59.86
13	ОПС -13	16	20	25	12	2	45	1,5	45	1,0	1,5	360	74.82
14	ОПС -14	16	20	25	25	2,5	45	1,5	45	1,0	1,5	360	123.96
15	ОПС -15	20	26	30	16	2	45	1,5	45	1,0	2,0	360	148.60

Избор на опора | Опора постоянна | Опора специална

Опора сферична

№	диус сфера	сочина@S	сочина анз	адус фаска	аметър ан	аметър ра	аметър мо	ска 1@Ske	адус фаска	сочина раб	@Revolve1	RP@Weigh
ОПСф- 1	5	6	0,5	45	2,5	5	3	0,25	45	2	360	0.47
ОПСф- 2	5	9	0,5	45	2,5	5	3	0,25	45	5	360	*0.12
ОПСф- 3	6	8	0,5	45	3	6	4	0,25	45	3	360	*0.13
ОПСф- 4	6	11	0,5	45	3	6	4	0,25	45	6	360	*0.22
ОПСф- 5	8	12	0,75	45	5	8	6	0,5	45	4	360	*0.39
ОПСф- 6	8	16	0,75	45	5	8	6	0,5	45	8	360	*0.59
ОПСф- 7	12	16	1	45	7	12	8	0,5	45	6	360	*1.07
ОПСф- 8	12	22	1	45	7	12	8	0,5	45	12	360	*1.75
ОПСф- 9	16	20	1,5	45	8,5	16	10	0,75	45	8	360	*2.29
ОПСф- 10	16	28	1,5	45	8,5	16	10	0,75	45	16	360	*3.90
ОПСф- 11	20	25	2	45	10	20	12	1	45	10	360	*4.32
ОПСф- 12	20	35	2	45	10	20	12	1	45	20	360	*7.46
ОПСф- 13	24	32	2,5	45	13	25	16	1,5	45	12	360	*8.80
ОПСф- 14	24	45	2,5	45	13	25	16	1,5	45	25	360	*15.18
ОПСф- 15	30	42	3	45	16	30	20	2	45	16	360	*17.52
ОПСф- 16	30	55	3	45	16	30	20	2	45	30	360	*27.10
ОПСф- 17	40	50	4	45	19	40	24	2,5	45	20	360	*34.30
ОПСф- 18	40	70	4	45	19	40	24	2,5	45	40	360	*59.44

Избор на опора | Опора постоянна | Опора специална

Опора специална

№	Означение	сочина анзац@Sketch2	адус фаска 1@Sketch2	аметър анзац@Sketch2	аметър работен@Sketch2	аметър монтажен@Sketch2	ска 1@Sketch2	адус фаска 2@Sketch2	@Sketch2	Sketch2	Sketch2	Sketch2	Sketch2	@Revolve1	RP@Weight
1	ОПСп- 1	1,5	45	8,5	15	10	0,75	45	4	18	30	3	12	360	21.63
2	ОПСп- 2	1,75	45	10	18	12	1	45	5	22	38	3	16	360	43.21
3	ОПСп- 3	2	45	13	22	16	1,5	45	5	26	46	4	20	360	83.37
4	ОПСп- 4	2,25	45	16	28	20	2	45	6	32	56	5	24	360	152.97
5	ОПСп- 5	2,5	45	20	34	25	2,5	45	6	38	68	6	30	360	283.43

Избор на опора | Опора постоянна | Опора специална | Опора сферична

***Fig. 4.5** Database for selecting base elements*

- ***Module*** "Optimization of locations schemes from the accuracy condition";
- ***Module*** "Optimization of location schemes from the reliability condition";
- ***Module*** "Choosing an location scheme from the condition of minimal costs for manufacturing the fixture";
- Output of the final results with a drawing of the LS.

The methodology is illustrated with an example given in an appendix to the dissertation.

GENERAL CONCLUSIONS AND FINDINGS

As a result of the work carried out, the goal of the dissertation work has been achieved - to develop a system for selecting the optimal scheme for location of workpieces during mechanical processing in CAD conditions - an environment that ensures the improvement of the technological preparation of production by reducing the cost of time and money when designing fixtures.

The following general conclusions and *findings* can be drawn :

1. A systematization of possible schemes for basing the workpieces in the fixtures for mechanical processing has been carried out with a view to their use in automated design.
2. An algorithm is proposed for automated selection of a rational identification scheme based on the indicators of accuracy, minimum auxiliary time and cost.
3. An analysis was conducted, with the help of which the criteria for: geometric compatibility were revealed, allowing the selection of a BS that satisfies the geometric shape of the workpiece; selection of BE structures when using different technological bases, from the point of view of their purpose and maintainability.
4. A methodology has been developed for selecting an optimal location scheme and its design and implementation depending on the required accuracy in processing and the required service life (interim repair period).
5. An algorithm has been developed and dependencies have been proposed for determining the dimensions of the base elements depending on the basing scheme.
6. As the main approach to solving the task of automating the selection of an optimal location scheme and its constructive implementation, the systematic approach is adopted, allowing to break down the entire optimization task into separate stages, to highlight the connections between them and the criteria for optimal search. To solve the task of automating the design of an optimal LS, an object-oriented approach is applied.
7. Obtained general model of an automated system for selecting the optimal location scheme in the fixtures for installing the workpieces using CAD systems based on three-dimensional solid modelling.

8. Models and algorithms for the automation of local tasks for the optimization of location schemes have been developed and databases necessary for their implementation have been formed.

9. Models have been developed for the operation of an automated system for designing fixtures for installing workpieces during mechanical processing in the form of class and state diagrams, which can be used to develop a software product for selecting an optimal locating scheme;

10. A structural diagram of the software package necessary for selecting an optimal establishment scheme has been developed;

11. A database with solid models of base elements and tables for their automated selection has been developed. The database allows the inclusion of new base element designs.

12. A methodology has been developed for the practical implementation of the automated system for selecting an optimal detection scheme.

13. The developed algorithms and methodology can be used to develop a software product that allows for the automation of routine activities related to the selection of an optimal scheme for setting up workpieces during mechanical processing.

CONTRIBUTIONS OF THE DISSERTATION

As a result of the work carried out, the following contributions have been *achieved:*

Scientific and applied contributions:

- Systematization of possible schemes for basing workpieces in location fixtures with a view to their use in automated design.
- The defined criteria for: geometric compatibility, allowing the selection of a basing scheme that satisfies the geometric shape of the workpiece; selection of BE structures when using different technological bases.
- The developed methodology, models, algorithms and class and state diagrams that can be used to develop a software product for selecting an optimal location scheme.

Applied contributions:

- The developed structural diagram of the software package for selecting the optimal location scheme.
- The developed database with solid models of base elements.
- Automated tables for: selection of models of base elements; preliminary assessment of the economic efficiency of the designed fixtures.

LIST OF PUBLICATIONS RELATED TO THE DISSERTATION

1. Metev N., Gitan A., Selection of optimal basic schemes in automatic design of fixtures for the locating of workpieces during machining. International scientific conference UNITECH '19, Gabrovo , Bulgaria 2019, vol . 2, p . 206-21 l . ISSN 1313-230 X.
2. Metev X. , Gitan A., Amudzhev I. Selection of an optimal scheme for locating the workpieces and determining the inaccuracy of basing in automated design of fixtures for locating the workpieces during mechanical processing, journal "Mechanical Engineering and Machine Science", issue 31, pp. 18-24, Varna, 2021. ISSN 1312-8612.
3. Metev N., Krumiv K., Gitan A., Selection of Locators in Automated Design of Fixtures for Locating Workpieces During Machining. Environment. Technology. Resources. Rezekne, Latvia, Proceedings of the 13th International Scientific and Practical Conference. Vol . 3, pp . 202-207. ISSN 2256-070 X (Scopus).
4. Gitan A. Program implementation of an automated system for selecting the optimal scheme for locating workpieces during mechanical processing, journal "Mechanical Engineering and Machine Science", issue 32, pp. 56-61, Varna, 2021. ISSN 1312-8612.
5. Gitan A. Metev X. Criteria for choosing an optimal location scheme in automated design of fixtures for installing of workpieces during mechanical processing. Youth Forum "Science, Technology, Innovation, Business - 21-22.11.2024, Plovdiv, Collection of Papers, 2024, pp. 111-116. ISSN 2367-8569

TITLE: OPTIMIZATION OF WORKPIECES LOCATION DURING MACHINING IN CAD ENVIRONMENT

Author: Eng. Ali Abdulkarim Gitan, MSc

ABSTRACT

The thesis investigates the issues related to the optimization of locating schemes for the workpieces up in machining using CAD systems.

An analysis and systematization of the locating schemes for the workpieces has been carried out and criteria for the selection of the locators have been defined, taking into account the conditions of geometrical compatibility, allowing the selection of a locating schemes satisfying the geometrical shape of the workpiece.

Methodology and algorithms for quality assurance of fixture design are developed based on selection of an optimal locating scheme the criteria of machining accuracy and reliability of the designed fixture.

A model for automation of the design of an optimal locating scheme and its constructive implementation using modern CAD systems based on the technology of three-dimensional solid parametric modelling is developed.

Developed is a structural diagram of the software package needed to select the optimal locating scheme. The main calculation modules of the system are presented in the form of separate dynamic libraries of functions.

A methodology for the practical implementation of the automated system for the selection of the optimal locating scheme has been developed, a database with solid models of the locators has been created, and tables for their automated selection have been developed.

Key words: fixtures for the locating, locating schemes for the workpieces, accuracy, inaccuracy of locating, reliability, automatic design.