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Inteligentni računalniški sistem za pomoč pri poučevanju konstruiranja

An Intelligent Computer System for Supporting Design Education

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Odločitve, sprejete v procesu konstruiranja, odločilno vplivajo na konkurenčnost izdelka na trgu. Zato sta zelo pomembni kakovost in uspešnost poučevanja konstruiranja na univerzitetnem študiju. V članku je predstavljen potek poučevanja konstruiranja, ki temelji na praktičnem skupinskem delu pri izdelavi projektne naloge. Opisane so težave, s katerimi se pri tem, predvsem zaradi svoje neizkušenosti, srečujejo študenti, in možnosti uporabe metod umetne inteligence za pomoč pri premagovanju teh težav. Podrobneje je opisan inteligentni računalniški sistem, ki naj študentom pomaga oceniti rezultate analize po metodi končnih elementov, jih pravilno razlagati in predstaviti kritična mesta v konstrukciji. Nadalje naj sistem študentom predlaga tudi ustrezne korake za izboljšanje konstrukcije. Za pravilno razumevanje rezultatov numerične analize in izbiro ustreznih konstrukcijskih ukrepov je treba veliko izkušenj in znanja. Obojega študentom primanjkuje, zato je uporaba metod umetne inteligence v tem primeru upravičena in lahko bistveno pripomore k učinkovitejšemu reševanju problemov.

(Ključne besede: konstruiranje, sistemi inteligentni, analize numerične, procesi učenja)

Decisions made in the design process have a significant influence on the competitiveness of a future product in the market. Therefore, the quality and success of design education at the university level is very important. This paper presents the process of design education, based on practical team work on project elaboration with an emphasis on the problems that appear, mostly due to the inexperience of students. The possibilities of applying artificial intelligence to solve these problems more efficiently are also discussed. An intelligent computer system to assist the students in evaluating the results of a finite-element analysis, correctly interpreting them and presenting the critical places in the structure, is described in detail. Moreover, the system should also suggest to the students the appropriate redesign actions to optimise the structure. To be able to properly understand the results of the numerical analysis and consequently choose the appropriate redesign steps, considerable knowledge and experience are required, which students tend not to possess. Thus, the use of artificial intelligence in this particular area makes sense and could help to overcome many problems more efficiently.

(Keywords: design, intelligent systems, numerical analysis, educational processes)

0 UVOD

Konstruiranje pomeni zapleteno in obsežno nalogo, ki ima v času moderne tehnologije zelo pomembno vlogo, saj lahko dandanes le najboljše rešitve prevladajo na tržišču. Glede na to je zelo pomembno, kako so osnovna načela konstruiranja predstavljena študentom in v kolikšni meri študenti spoznajo proces konstruiranja in njegovo obsežnost. Študij procesa konstruiranja na Fakulteti za strojništvo Univerze v Mariboru že nekaj časa poteka na temelju praktične izdelave projekta v majhnih skupinah. Med poukom strojništva študenti pridobijo različna znanja, ki jih morajo uporabiti pri predmetu

0 INTRODUCTION

Design is a very complex and wide-ranging task that has a very important role in modern high technology, where only the best solutions will succeed in the market. It is therefore very important how the fundamental principles of design are presented to students and to what extent the students become aware of the design process and its complexity. For some time the teaching of design at the Faculty of Mechanical Engineering at the University of Maribor has been based mainly on practical team work. Through the mechanical engineering educational process the students obtain a variety of knowledge that "metode konstruiranja". Namen predmeta o konstruiranju ni le naučiti študente, kako izvesti proces konstruiranja, temveč tudi ugotoviti, ali so, in v kolikšni meri, študenti zmožni rešiti resnični problem iz prakse. Poleg tega želimo pri študentih spodbuditi tudi lastnosti, kakor so iznajdljivost, domiselnost, ustvarjalnost in samozavest. Celoten proces konstruiranja skušamo simulirati z izdelavo projekta v majhnih skupinah. Asistent vodi študente tako, da s sistematičnim delom in z lastnimi zmožnostmi izdelajo izbrani projekt.

Med projektnimi vajami študenti pridobijo znanje o novih metodah in orodjih konstruiranja, ki povečujejo ustvarjalnost in produktivnost ter lahko pomagajo izboljševati kakovost novih izdelkov. Študenti navadno končajo projekt zelo uspešno in so s potekom vaj zelo zadovoljni. Običajno smo nad njihovim znanjem in rezultati presenečeni, saj so zelo ustvarjalni in iznajdljivi. Vendar pa nimajo praktičnih izkušenj, kar je še posebej očitno predvsem v drugi polovici procesa konstruiranja, ko morajo pregledati in oceniti izbrani osnutek konstrukcije. Uporaba metod umetne inteligence v obliki inteligentnega svetovalnega računalniškega sistema bi lahko bila v tem primeru zelo koristna. Prispevek podaja kratek pregled procesa (poučevanja) konstruiranja in nekaj zamisli za uporabo metod umetne inteligence v tem procesu.

1 PROCES (POUKA) KONSTRUIRANJA IN PROJEKT

Projekt se prične z definicijo problema. V našem primeru pouka konstruiranja skupina šestih ali sedmih študentov skupaj z asistentom definira zanimiv problem – projekt, ki še ni bil rešen. Njihova osnovna naloga je najti optimalno tehnično rešitev za novi izdelek [1]. Vloga asistenta je voditi študente skozi sistematični proces in simulirati proces konstruiranja, kakor se ta odvija v praksi. Proces konstruiranja sledi osnovnim zamislim Pahla in Beitza [2], ki izhajajo iz tradicionalnega konstruiranja. Za proces konstruiranja je značilno napredovanje po korakih. Obstajajo štirje osnovni koraki oz. faze procesa konstruiranja: razjasnitev/specifikacija naloge, konstruiranje osnutka, snovanje konstrukcije in razdelava podrobnosti.

Prva faza, specifikacija naloge, ima zelo velik vpliv na zahtevnost novega izdelka in njegovo ekonomsko uspešnost. Študenti, otroci novega časa, imajo običajno različne potrebe, želje ali zahteve in tako veliko zamisli za projekte, še posebej ker niso omejeni s sedanjimi rešitvami.

Iskanje čim več variantnih rešitev problema je glavni cilj naslednje faze – konstruiranja osnutka. Z uporabo novih metod konstruiranja, ki so primerne za skupinsko delo, in v sproščenem, svobodomiselnem ozračju študenti običajno razvijejo veliko število idejnih rešitev problema. Ustvarjalnost in

should be used in a subject named "design principles". The purpose of the design course is not only to teach students how to under take design, but also to ascertain if the students are capable of solving a real-life problem. Moreover, the aim is also to stimulate the students' inventiveness, creativeness and self-confidence. The whole design process is simulated with the practical team work on project elaboration. The teacher should guide the students to use their own abilities to elaborate the project through systematic work.

Through project-based exercises the students acquire modern design methods and tools, which increase creativity and productivity, and can help to improve the quality of new products. The project elaboration for the students is usually very successful and the students are very satisfied with the course of exercises. They usually present knowledge and results, which are unexpected, as they are very creative and innovative. On the other hand, they have lack of experience, which is especially obvious in the second part of the design process, when the students should examine and verify their proposed design solution. The use of artificial-intelligence methods in the form of an intelligent advisory computer system can be very helpful in this case. A short review of the design (education) process and some ideas for applying artificial-intelligence methods within this process are presented in this paper.

1 PROJECT–BASED DESIGN (EDUCATION) PROCESS

A project begins with a problem definition. In our example of design education a small group of six or seven students together with an assistant lecturer define an interesting problem – the project, which has not been solved yet. Their main goal is to find the best possible technical solution for the new product [1]. The lecturer's role is to guide the students through the systematic process and simulate a real-life design process. The design process follows the main ideas of Phal and Beitz [2], based on traditional design. The design progresses in a step-by-step manner. There are four main steps or phases: clarification/specification of the task, conceptual design, embodiment design and detail design.

The first phase, specification of the task, has a great influence on the pretentiousness of the new product and its economic success. The students have a lot of project ideas, and are not handicapped with experience of existing solutions.

Looking for as many solution variants as possible is the main goal in the next phase of the problem – conceptual design. With an open mind and modern design methods, suitable for the group work, the students usually generate a very wide range of solution ideas. The students' inventiveness and domiselnost študentov sta najbolj zaželeni dejavnosti v fazi konstruiranja osnutka. Rezultat objektivne ocene vseh idejnih rešitev je "optimalna" tehnična rešitev, ki je izhodišče za naslednjo fazo.

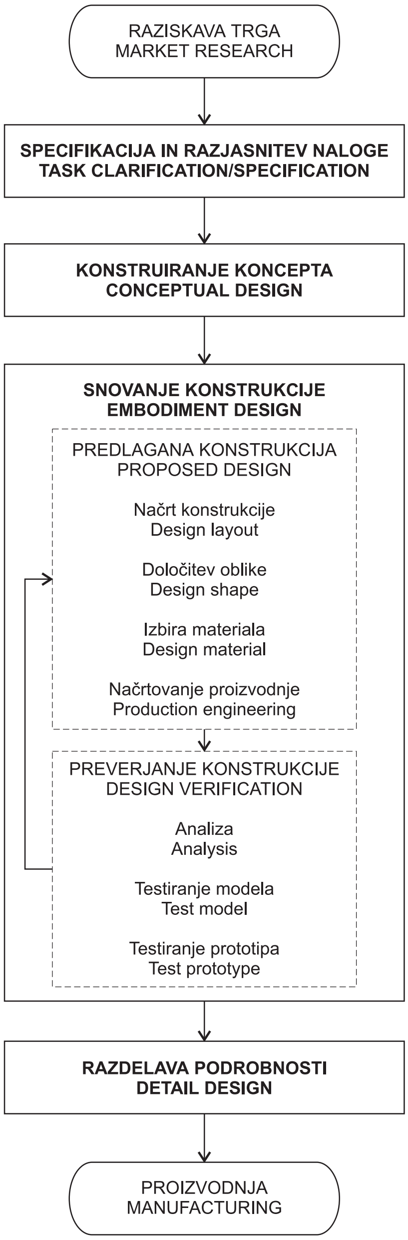
V fazi snovanja konstrukcije študenti določijo obliko in načrt novega izdelka. Mimo tega morajo študenti tudi preveriti izbrano različico izdelka. Študenti korakoma razvijajo tehnično rešitev izdelka. V številnih korakih, na podlagi analize in sinteze, vedno znova spreminjajo in dopolnjujejo trenutno verzijo izdelka.

Končni videz konstrukcije je osnova za izdelavo načrtov in druge dokumentacije za proizvodnjo, ki jo študenti izdelajo v zadnji fazi – razdelavi podrobnosti. Predstavljen postopek konstruiranja je prikazan na sliki 1.

creativity are the most welcome activities in the conceptual design phase. The "optimal" solution variant of the design is selected by an objective evaluation.

In the next phase - embodiment design, the students determine the design layout and the form of the new product. In addition, they should also verify the selected variant of the design. Step by step, the students develop a technical product. During many corrective steps, using analysis and synthesis, they constantly alternate and complement each preliminary layout.

The final design is a basis for all drawings and other production documents that are made in the last, detailed, design phase. The presented design process is shown in Figure 1.



Sl. 1. *Glavne faze postopka konstruiranja*
Fig. 1. *The main phases in the design process*

Postopek spreminjanja, izboljšanja konstrukcije v fazi snovanja terja od študentov veliko znanja o mehaniki, sestavah in tehnologiji materialov. Pomanjkanje izkušenj je zelo pogosto. Kljub temu pa so študenti zmožni razviti kar dobre konstrukcije. Širok ustvarjalni duh, brez zadržkov, ki jih imajo običajno bolj izkušeni konstrukterji, omogoča študentom, da razvijejo konstrukcije zanimivih oblik in izvedb. Izbira ustreznega materiala je zanje že nekoliko težja naloga.

Prvi večji uspeh za študente pomeni predlagana izvedba novega izdelka. Ali je predlagana konstrukcija preveč, ali premalo dimenzionirana, pa žal študenti zaradi pomanjkanja izkušenj ne vedo. Če je konstrukcija predimenzionirana, je lahko pretežka ali predraga. V primeru premalo dimenzionirane konstrukcije pa obstaja verjetnost porušitve pri uporabi. Zato morajo študenti predlagano konstrukcijo preveriti.

Dandanes od študentov pričakujemo, da uporabljajo moderna orodja, to so sistemi za računalniško podprto konstruiranje (RPK - CAD). Modeliranje predlagane konstrukcije je običajno zelo učinkovito. Obstoječi geometrijski oblikovalniki so uporabniško zelo prijazni. Študenti z navdušenjem uporabljajo pripomočke, kakor so: premikanje, rotiranje, senčenje, sestavljanje itn. Razmere v konstrukciji med njeno uporabo lahko simuliramo in preverjamo z uporabo analize po metodi končnih elementov (MKE), ki je običajno del sistema RPK. MKE je najbolj pogosto uporabljena numerična metoda za analize napetosti in deformacij v fizikalnih sestavah. V bistvu te analize omogočajo študentom, da bolje razumejo obnašanje konstrukcije in jim dajejo smernice za optimizacijo konstrukcije. Vendar študenti običajno ne poznajo osnovnih načel MKE. Poleg tega so neizkušeni. Zaradi tega morajo rešiti številne probleme preden definirajo končno izvedbo konstrukcije. Najprej imajo študenti težave s pripravo mreže končnih elementov, ki predstavlja idealiziran model dejanske konstrukcije. Naslednji problem predstavlja ustrezna razlaga rezultatov analize. In nazadnje, študenti ne vedo, kateri ukrepi in spremembe konstrukcije so nujni in bodo zadovoljili dane zahteve.

Večino teh problemov bi lahko bolje obvladovali z uporabo inteligentnega svetovalnega sistema za podporo pri ključnih odločitvah pri procesu analize konstrukcije [3]. Prvi modul predlaganega sistema, ekspertni sistem za pomoč pri gradnji mreže končnih elementov, je že bil razvit v našem laboratoriju ([4] in [5]). Šolsko verzijo tega sistema poskusno uporabljamo na naši fakulteti, predvsem v pedagoške namene. Danes nekateri programski paketi MKE že vsebujejo bolj ali manj inteligentne module, ki vodijo neizkušenega uporabnika skozi proces analize. Ob podpori visoke tehnologije računalniške grafike večina paketov

The improving process, or redesign, in the embodiment design phase, demands from the students a lot of knowledge about the principles of mechanics, structures and materials technology. A lack of experiences is very common, however, they are able to define quite good designs. With a lot of imagination and not so many restrictions as the more experienced designers usually have, they create interesting design shapes and forms. But the definition of a proper material is a more difficult task for them.

The proposed design of the new product is the first big success for the students. However, as they are inexperienced, they do not know whether their proposed design is over- or under-sized. In the case of the design being over-sized it can be too heavy or too expensive. On the other hand, an under-sized structure can break during use. Therefore, it is necessary for the students to verify the proposed design.

Nowadays, it is expected that the students will use modern tools like Computer Aided Design (CAD) systems. Modelling of the proposed design is mostly very efficient. The existing geometric modellers are very user friendly. The students use facilities like moving, rotating, shading, assembly, etc. with enthusiasm. Simulation and verification of the conditions within the structure during its exploitation can be performed with the Finite Element Method (FEM), which usually forms part of the CAD system. FEM is the most frequently used numerical method to analyse stresses and deformations in physical structures. Indeed, the analysis can provide the students with a greater understanding of how a structure behaves and give them guidelines for the optimisation of the design. However, the students do not understand very well, the basic principles of FEM; they are also inexperienced. Consequently, they should solve a lot of problems on the way to the adequate design definition. First of all, they do not have experiences in how to prepare the appropriate finite-element mesh model – the idealised real design. The next problem is the adequate interpretation of the analysis' results. And finally, the students do not know what actions and which changes to the design are necessary to satisfy the given criteria.

Most of these problems can be overcome with the use of an intelligent advisory system for overall support to the key decisions within the analysis process [3]. The first module of the proposed system, an expert system for intelligent finite-element mesh design has already been developed in our laboratory ([4] and [5]). The academic version of it is already in experimental use at our faculty, mostly for educational purposes. At the present time, some of the FEM packages already have more-or-less intelligent modules for guiding inexperienced users through the analysis process. Supported by high computer graphics technology they also offer a very good omogoča tudi zelo dober grafični prikaz. Kljub temu pa to ni dovolj učinkovito. Študenti potrebujejo tudi navodila, ki izhajajo iz izkušenj. Namen našega raziskovalnega dela v prihodnje je odkriti znanje, ki izhaja iz izkušenj in ga vključiti v inteligentni računalniški sistem.

2 OPTIMIZACIJA OBLIKE KONSTRUKCIJE

Grafični prikaz rezultatov numerične analize ponazarja porazdelitev, obliko in velikost deformacij in napetosti v konstrukciji. Na podlagi takšne predstavitve, mora konstrukter/študent ugotoviti, ali konstrukcija izpolnjuje zahteve, oziroma kateri so tisti konstrukcijski koraki, s katerimi je mogoče konstrukcijo izboljšati. To je zelo zahteven in pomemben del procesa konstruiranja. Izbira drugačnega materiala je običajno najlaže izvedljiva sprememba, ki pa žal ni vedno uspešna. Izbira boljšega (dražjega) materiala je velikokrat tudi ekonomsko neupravičena. Zaradi pomanjkanja praktičnih izkušenj študenti običajno uporabljajo teoretično znanje in iščejo pomoč pri izkušenih konstrukterjih – ekspertih. Slika 2 prikazuje primer predlagane konstrukcijske rešitve in možnosti za njeno optimizacijo.

Odveč je poudarjati, da je običajno mogočih več različnih konstrukcijskih korakov za izboljšanje konstrukcije. Izbira koraka je odvisna od zahtev, možnosti in tudi želja. Računalniški sistem, ki bi vseboval znanje o spreminjanju konstrukcij in bi lahko svetoval ter razlagal ustrezne konstrukcijske spremembe, bi bil v veliko pomoč. Zato obstaja velika utemeljitev za razvoj in vključitev takšnega inteligentnega sistema v izobraževalni proces.

3 INTELIGENTNI SISTEM ZA OPTIMIZACIJO KONSTRUKCIJ

V tehnični praksi je izvedba optimalne konstrukcije v prvem poskusu zelo redka. Konstruiranje je ponavljajoč se proces. Število potrebnih ponovitev je odvisno predvsem od kakovosti začetnega predloga konstrukcije in ustreznosti kasnejših konstrukcijskih sprememb. Kakovost in pravilnost izbrane spremembe konstrukcije sta odvisni od znanja in izkušenj. Razvoj inteligentnega sistema za pomoč pri poučevanju konstruiranja načrtuje zapis znanja in izkušenj, potrebnih za kakovostno spreminjanje konstrukcij, v obliki, ki jo lahko uporablja računalniški sistem.

Nedvomno bo razvoj predlaganega inteligentnega sistema pomenil zapleteno in zahtevno raziskovalno nalogo. Najprej je treba definirati vhodne podatke. Poleg danih kriterijev, zahtev in vseh osnovnih parametrov o samem problemu: geometrijske oblike, obremenitev in robnih pogojev, bodo vhodni podatki vsebovali tudi rezultate analize

graphical presentation. Nevertheless, this is not enough for the students, who also need instructions, which come from experience. The aim of our future research is to discover the knowledge in the form of experience and include it in the intelligent computer system.

2 OPTIMISING PROCESS – REDESIGN

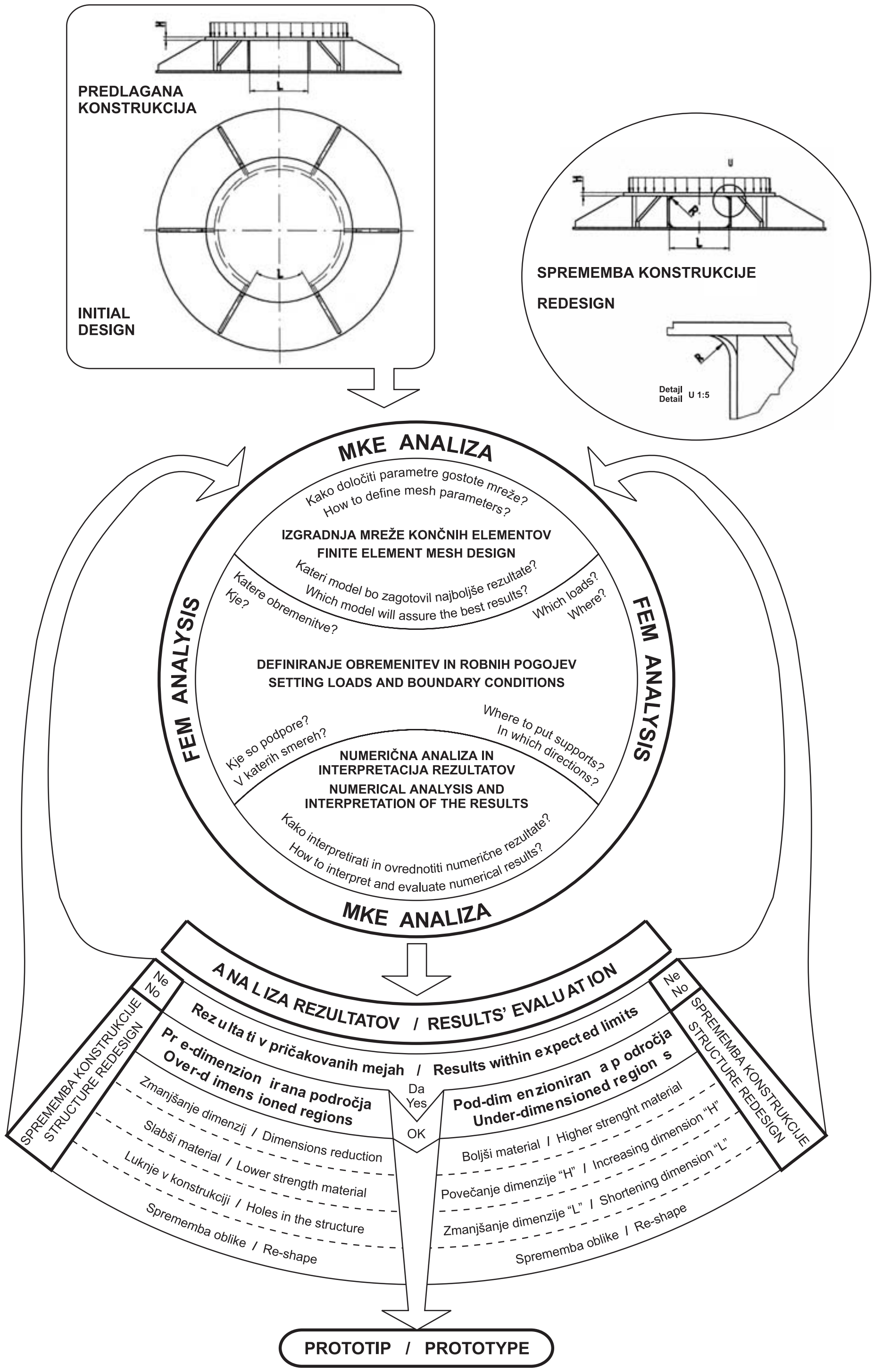
Graphical representation of numerical analysis' results represents a distribution, the form and size of displacements and stresses within the structure. With that kind of representation the designer/student should confirm that the structure meets the requirements or choose the appropriate design steps to improve the initial design. This is a very difficult and important part of the design process. Selecting a different material is usually the easiest way to change the structure, but this is not always successful. Moreover, selecting a better (more expensive) material is often economically unjustified. Due to a lack of practical experience students mostly use theoretical knowledge and look for help from experienced designers – experts. Figure 2 presents an example of the proposed initial design and possibilities for optimisation – redesign.

Usually, several different redesign steps are possible for improving the design. The choice of redesign action depends on the requirements, possibilities and also on wishes. A computer system with encoded redesign knowledge, that could advise and explain the appropriate redesign actions, would be very helpful. For this reason, there exists a great motivation to develop such an intelligent redesign system and include it in the education process.

3 INTELLIGENT REDESIGN SYSTEM

An optimal design achieved at the first attempt is very rare in engineering. Design is an iterative process. The number of iterations/cycles needed mostly depends on the quality of the initial design and adequacy of the redesign actions. The quality and correctness of a selected redesign action are dependent on knowledge and experience. The development of an intelligent system for supporting design education anticipates the encoding of the knowledge and experiences required for quality redesign in a form that could be used by a computer system.

Undoubtedly, the development of the proposed intelligent system will be a complex and exacting research task. First of all, we should define the input data. Beside given criteria, demands and all basic parameters about the problem in terms of geometry, loads and boundary conditions, the input data will include the results of the FEM analysis. The investigation of the analysis' results should be per-



Sl. 2. *Predlagana konstrukcija in ustrezni nadaljnji konstrukcijski koraki*
Fig. 2. *Initial design and appropriate further design actions*

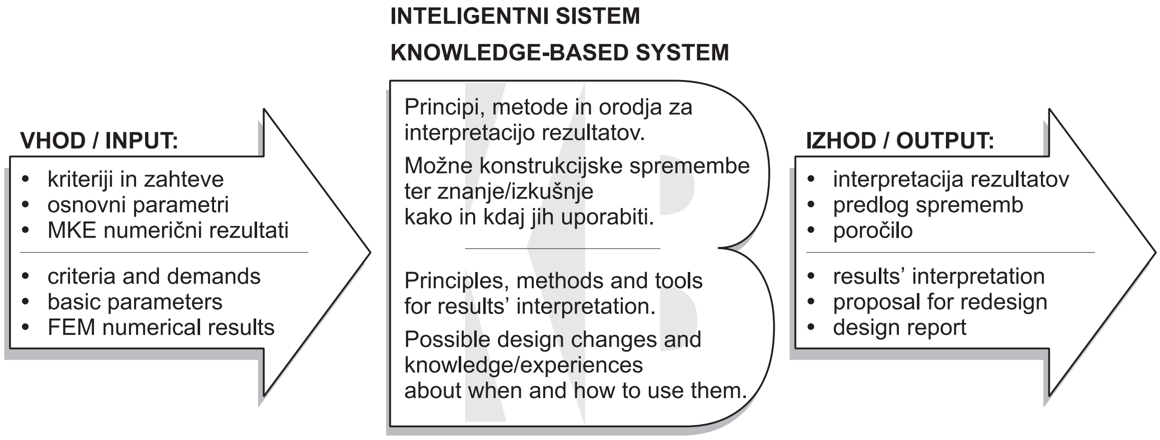
MKE. Prav obravnava rezultatov analize mora biti izvedena skrbno in temeljito, saj lahko le pravilna razlaga rezultatov zagotovi ustrezno izbiro potrebnih sprememb konstrukcije. Pojavi se tudi vprašanje, kako ločiti in prenesti najpomembnejše rezultate (kritična mesta) iz zapletene in obsežne datoteke v inteligentni sistem in kakšno obliko zapisa uporabiti. Preučiti moramo vse teoretično in praktično znanje

formed fully and carefully. Only a correct interpretation of the results can ensure the accurate selection of redesign actions. Another question is how to separate and transfer the important part of the numerical results (critical places) from a complex and extensive file to the intelligent system and which form should be used. We should also study all theoretical and practical knowledge about redesign. An examinao spreminjanju konstrukcij. Zelo uporabna bo raziskava sedanjih poročil o izvedenih konstrukcijskih spremembah. V tem primeru bi lahko uporabili avtomatično učenje kot zelo uporabno metodo za gradnjo baze znanja. Veliko praktičnega znanja lahko pridobimo tudi z intervjuji ekspertov. Intervjuji in proučevanje poročil o konstrukcijskih spremembah so odvisni od sodelovanja različnih strokovnjakov in lahko trajajo precej časa. Sledilo bo oblikovanje pravil, ki bodo predstavljala ‘osvojeno’ znanje in izkušnje. Največjo nevarnost v načrtu razvoja sistema pomeni obsežnost procesa konstruiranja, saj bi kaj lahko zašli s poti. Glede na vse to bi bilo dobro, da se vsaj na začetku omejimo na temeljni in tipični konstrukcijski proces, kakor je to primer tudi pri poučevanju. Razširitev sedanjega sistema na širše področje uporabe ne bi smelo delati težav.

Slika 3 prikazuje osnovno arhitekturo predlaganega inteligentnega, ekspertnega sistema za pomoč pri poučevanju konstruiranja.

tion of the existing old redesign elaborates will be very useful. In this case, we could use machine learning as a very useful method for building a knowledge base. A lot of practical knowledge can be acquired by interviewing experts. Interviewing and investigating the old redesign elaborates is conditional on the co-operation of several experts and can be time-consuming. After that, we should find out the rules for the presentation of the knowledge and experiences acquired. The complexity of the design process is the weakest part in the system development plan, as we could easily lose the way. Considering this, we should, at least at the start, limit our research to the elementary and typical design process, which is also the case at the beginning of the educational process. It should not be a problem to extend the existing system to a wider area of application.

Figure 3 shows the basic architecture of the proposed intelligent knowledge-based system for supporting design education.



Sl. 3. *Inteligentni sistem za optimizacijo konstrukcij*
Fig. 3. *Intelligent redesign system*

4 SKLEP

Ideja o inteligentnem računalniškem sistemu za optimizacijo konstrukcij je rezultat izkušenj, pridobljenih med poučevanjem procesa konstruiranja in predhodnega razvoja inteligentnega sistema za gradnjo mreže končnih elementov. Namen našega raziskovalnega dela v prihodnje je razviti sistem, ki bo lahko uporabniku/študentu v pomoč pri ocenitvi rezultatov analize po MKE, njihovi razlagi in predstavitvi kritičnih mest v konstrukciji. Na koncu mora sistem študentom predlagati tudi ustrezne korake za izboljšanje konstrukcije. Pri tem je treba upoštevati premalo pa tudi preveč dimenzionirana področja konstrukcije.

Trenutno proučujemo rezultate analiz MKE ter vpliv določenih sprememb konstrukcij. Hkrati poskušamo najti ustrezne primere osnovnih začetnih konstrukcij. Menimo, da bo predstavljeni inteligentni sistem zelo uporaben pri študiju procesa

4 CONCLUSION

The idea of an intelligent redesign computer system is the result of experiences acquired through the design education process and the previous development of intelligent systems for finite-element mesh design. The aim of our future research work is to develop a system, which will be able to help the user/student to evaluate the results of FEM analysis, correctly interpret them and present the critical places in the structure. At the end, the system should also suggest to the students the appropriate redesign actions to optimise the structure. The system should consider under-dimensioned as well as over-dimensioned places in the structure.

At present, we have examined results of the FEM analyses and the influence of some redesign actions. We have also tried to find convenient examples of elementary initial design. We believe the intelligent system application will be very useful in konstruiranja. Lastnost ekspertnih sistemov, ki so z odgovori na vprašanja: 'Kako?' in 'Zakaj?' zmožni pojasnjevati delovanje mehanizma sklepanja, je še posebej dobrodošla, saj lahko študentom omogoči pridobivanje novih znanj. Še več, uporaba predlaganega sistema bi bila gotovo dobrodošla tudi pri konstruiranju v praksi.

the design-education process. The ability of the knowledge-based systems that explain the inference process by answering the questions "How" and "Why" could be especially welcome, as it can enable the students to acquire some new knowledge. Moreover, the use of the proposed system would certainly be welcome in the practical design process too.

5 LITERATURA
5 REFERENCES

[1] Novak, M., B. Dolšak (1998) Project-based design learning, *Proceedings of the International Workshop PDE Pedagogics in Design Education*, Pilsen, Czech Republic, 7 strani.

[2] Pahl, G., W. Beitz (1996) Engineering Design – A systematic approach, *Springer Verlag*.

[3] Dolšak, B., Novak, M., A. Jezernik. (1997) Expert systems in design, *Proceedings of the Third International Conference: Design to Manufacture in Modern Industry (Edited by Jezernik, A. & Dolšak, B.)*, Portorož, Slovenia, Faculty of Mechanical Engineering, Maribor.

[4] Dolšak, B., A. Jezernik (1998) A Rule-Based Expert System for Finite Element Mesh Design, *Proceedings of the 5th International Design Conference - DESIGN'98 (Edited by Marjanović, D.)* – Dubrovnik.

[5] Dolšak, B., Bratko, I., A. Jezernik (1998) Application of Machine Learning in Finite Element Computation, *Machine Learning, Data Mining and Knowledge Discovery: Methods and Applications (Edited by R.R. Michalski, I. Bratko and M. Kubat), John Wiley & Sons*.

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